

Type	L#	Hits	Search Text	DBS	Time Stamp	Comments	Error Definitions
1	BRS	L1	48904 handheld (hand adj held)	USPAT	2002/08/12 09:13		0
2	BRS	L2	1525574 biometric iris retina\$2 fingerprint (finger adj print) faces3	USPAT	2002/08/12 09:15		0
3	BRS	L3	668637 security verif\$ identif\$ auth\$	USPAT	2002/08/12 09:17		0
4	BRS	L4	78485 2 same 3	USPAT	2002/08/12 09:17		0
5	BRS	L5	2998 4 and 1	USPAT	2002/08/12 09:17		0
6	BRS	L6	229 4 same 1	USPAT	2002/08/12 09:18		0



US006377699B1

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(12) **United States Patent**
Musgrave et al.

(10) Patent No.: **US 6,377,699 B1**
(45) Date of Patent: **Apr. 23, 2002**

(54) **IRIS IMAGING TELEPHONE SECURITY MODULE AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/199,369**

(22) Filed: **Nov. 25, 1998**

(51) Int. Cl.⁷ **G06K 9/00; H04M 11/00**

(52) U.S. Cl. **382/117; 340/5.82; 379/93.03; 382/115; 455/411**

(58) Field of Search **382/115, 116, 382/117-118; 379/93.02, 93.03, 445; 380/247; 713/186; 455/410, 411; 340/5.8-5.83**

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Primary Examiner—Bhavesh Mehta

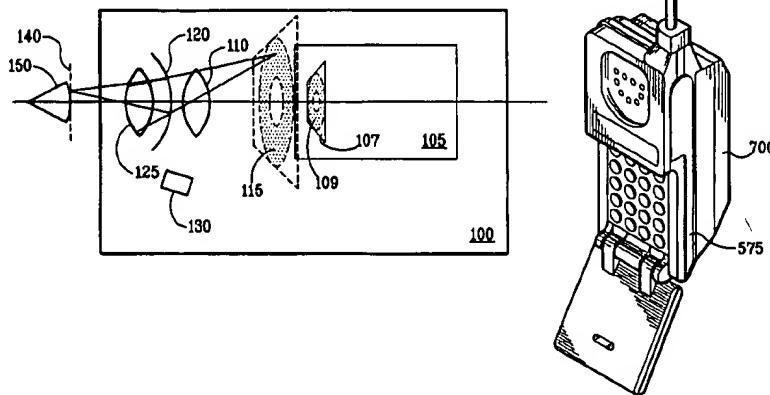
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(57)

ABSTRACT

A compact, handheld imaging apparatus which can be used to capture high-quality iris images for identification of a person. The handheld iris imager is non-invasive and non-contacting and comprises a camera, a cold mirror, a lens, and an illuminator. The imager has sensors and indicators which assist a user in aligning and focusing the device. The imager also automatically captures the image when proper positioning is achieved. A template of the image is then compared to a database of previously stored templates of images to identify the person. The imager is integrated into a telephone as a security module. The telephone cannot be unlocked and used unless a user has been identified and authorized by the imager.

33 Claims, 6 Drawing Sheets



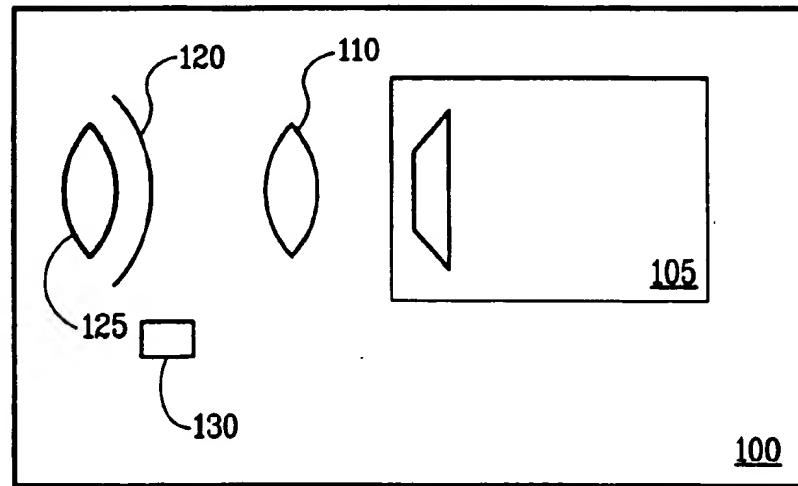


FIG. 1

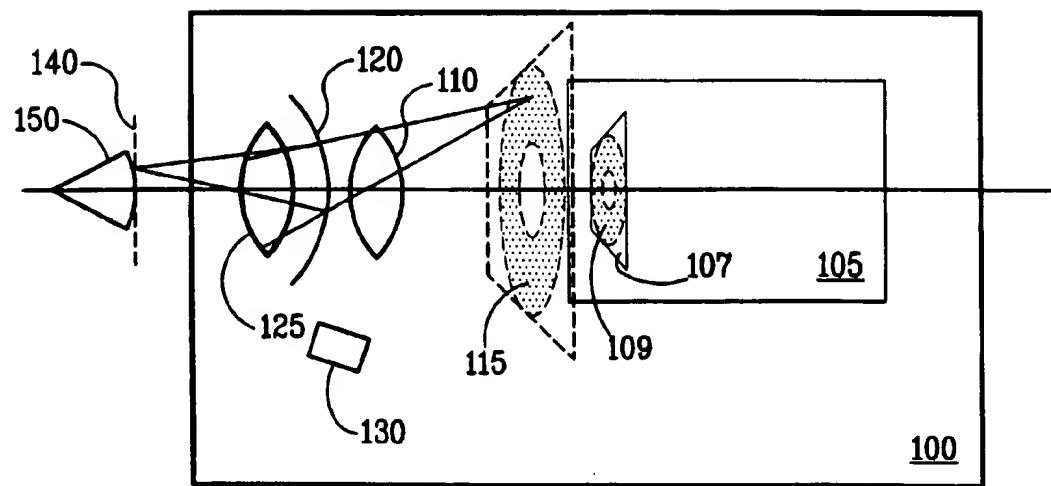


FIG. 2A

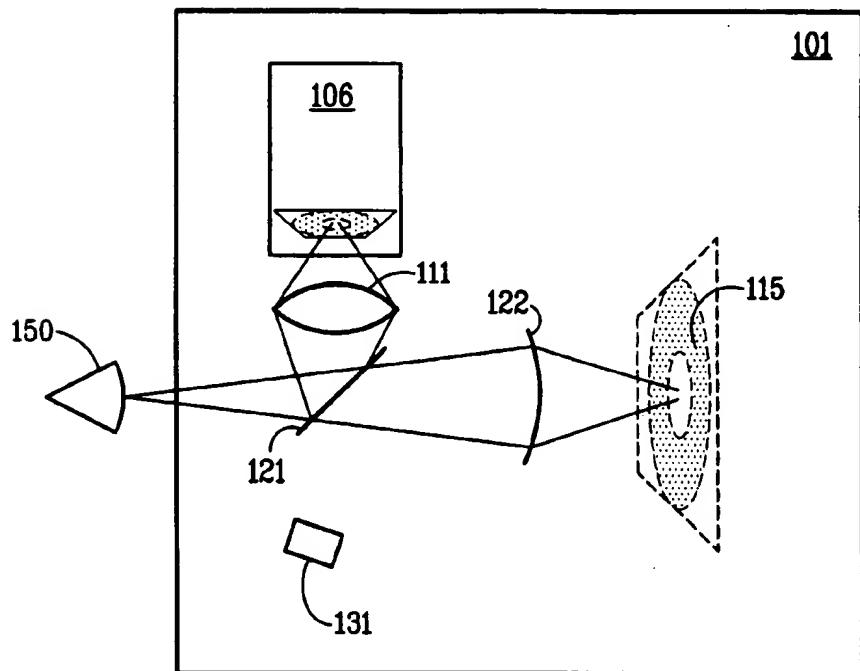


FIG. 2B

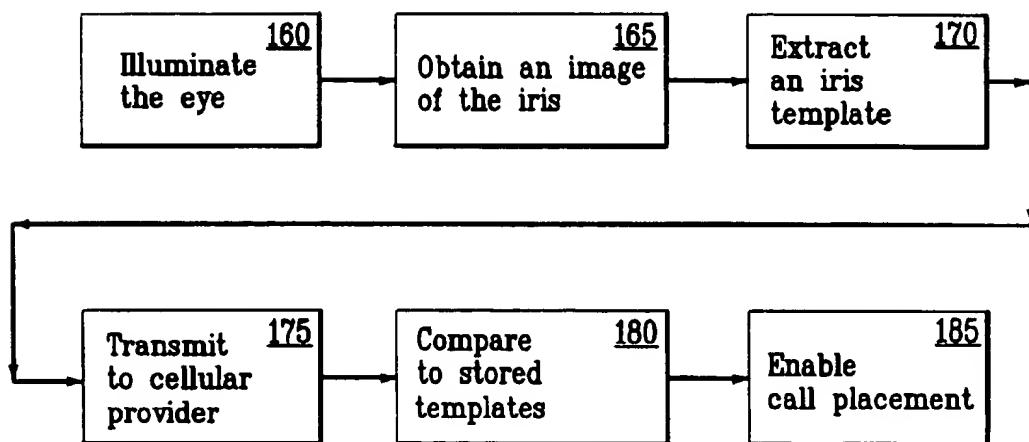
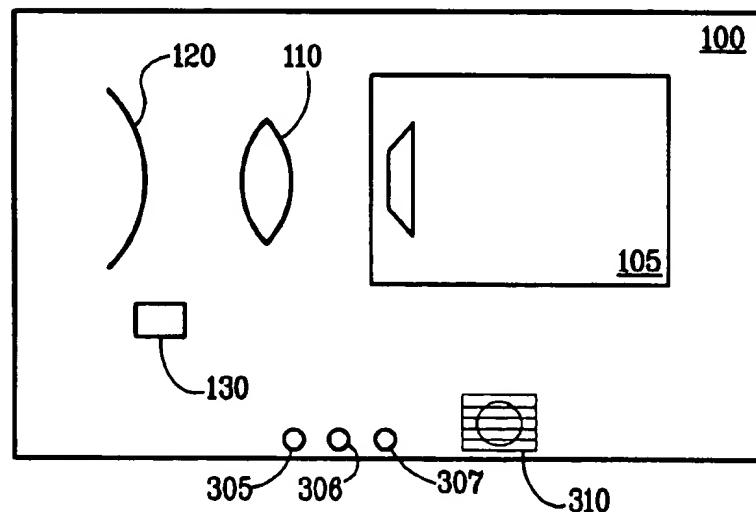
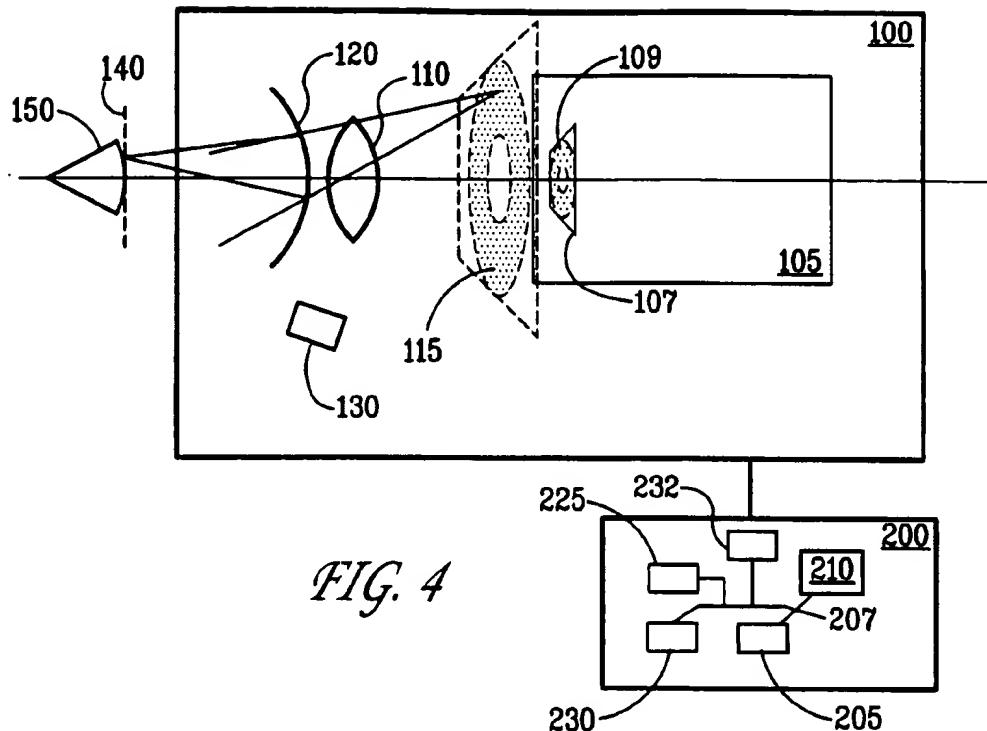


FIG. 3



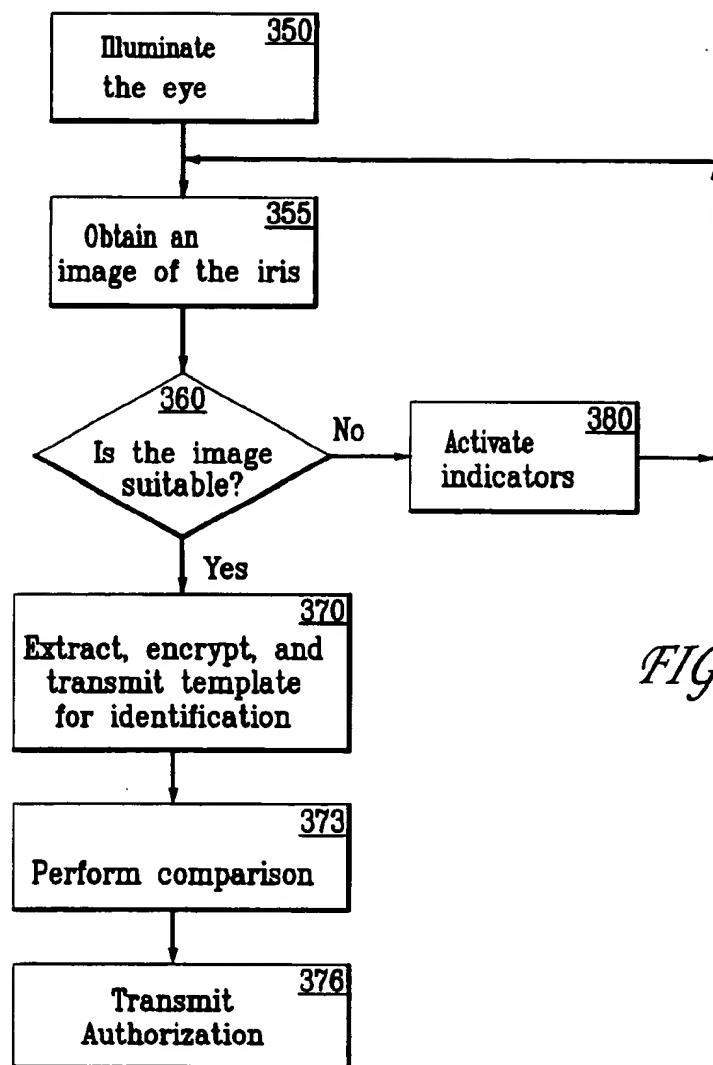


FIG. 6

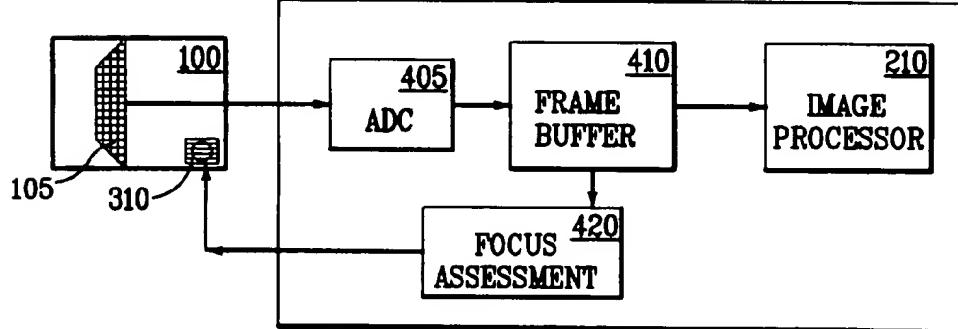


FIG. 7

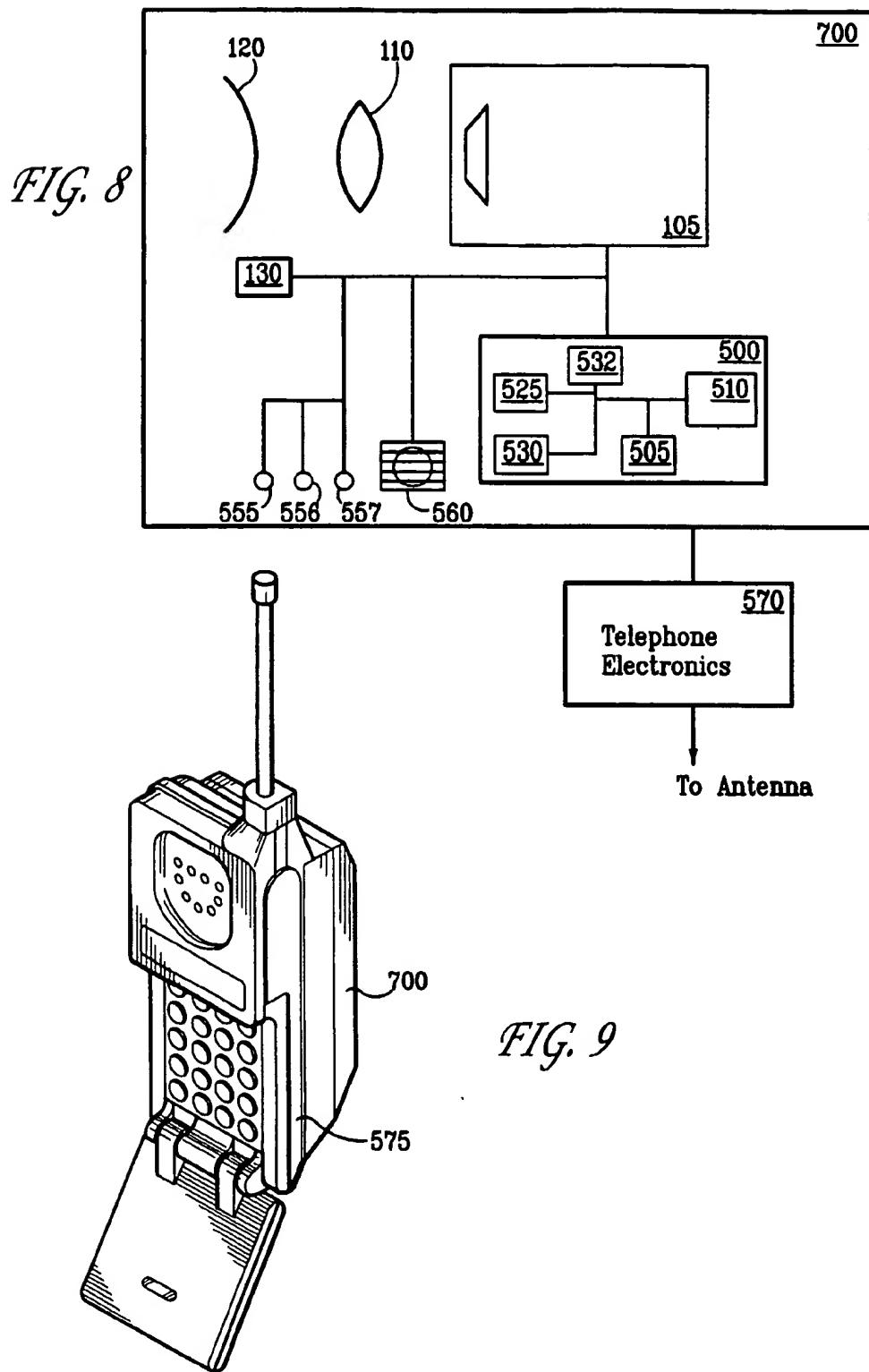
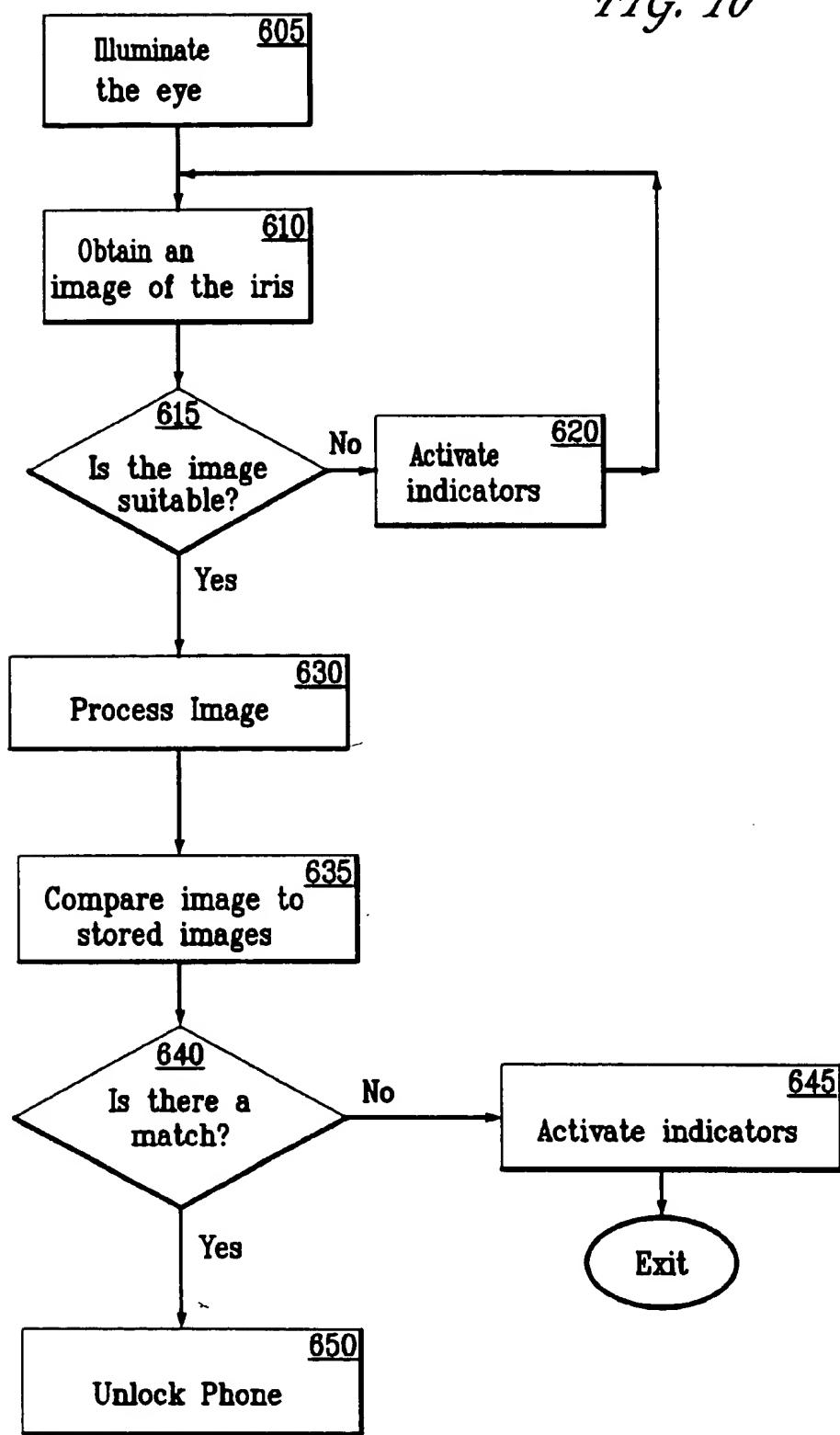


FIG. 10



IRIS IMAGING TELEPHONE SECURITY MODULE AND METHOD

FIELD OF THE INVENTION

The present invention relates in general to identification of physical characteristics of a human being or other animal. More particularly, the present invention relates to iris recognition.

BACKGROUND OF THE INVENTION

Various technologies are used for uniquely identifying a person in accordance with an examination of particular attributes of either the person's interior or exterior eye. One of these technologies involves the visual examination of the particular attributes of the exterior of the iris of at least one of the person's eyes. The iris of the human eye has random patterns of striations, ciliary processes, crypts, rings, furrows and other features which had been shown capable of generating highly unique biometric templates for personal identification. In this regard, reference is made to U.S. Pat. No. 4,641,349, "Iris Recognition System", issued to Flom et al., and U.S. Pat. No. 5,291,560, "Biometric Personal Identification System Based on Iris Analysis", issued to Daugman. As made clear by these patents, the visible texture of a person's iris can be used to distinguish one person from another with great accuracy. Thus, iris recognition can be used for such purposes as controlling access to a secure facility or a bank automatic teller machine, for example. An iris recognition system involves the use of an imager to video image the iris of each person attempting access, and image processing means for comparing this iris video image with a reference iris image on file in a database.

Iris identification systems have been developed that are capable of collecting images of the iris and processing them to produce biometric templates. These templates may be used to identify individual irises with extremely low error rates, on the order of 1 in 10^{78} . The systems capture the iris images using stationary optical platforms that are often large, complex, and expensive. The systems are difficult to use with minimal cooperation of the subject being identified. As a result their usefulness in many applications is limited.

The cellular telephone industry each year loses an estimated \$650 million to cellular fraud, principally due to cloning of cellular telephones. Cloning involves re-programming a phone's electronic serial number and telephone number to those stolen from a legitimate subscriber. To counteract cloning, some service providers have utilized personal authentication techniques such as personal identification numbers (PIN) or voice verification to verify that the authorized subscriber is using the phone. This is unreliable because PIN number can be stolen or forgotten, and voice verification messages may be recorded.

Although the art of human recognition systems is well developed, there remain some problems inherent in this technology, particularly the lack of an iris imager and security module suitable for integration into a cellular telephone, and the lack of a method for using biometric information for enabling access to the cellular network. Therefore, a need exists for a recognition system that overcomes the drawbacks of the prior art.

SUMMARY OF THE INVENTION

The present invention is directed to a telephone security module comprising: iris acquisition means having a front surface for obtaining an image of an iris of an eye; a lens

having a image plane disposed in front of the front surface of the iris acquisition means; a mirror disposed on a side of the lens opposite the iris acquisition means; an illuminator disposed along a side of the mirror; a memory for storing an iris image obtained by the iris acquisition means; a processor for extracting a template from the stored iris image; and a communications interface for transmitting the template to a central station.

According to one aspect of the invention, the iris acquisition means comprises a camera, and the mirror is a cold mirror. The camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm. The mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

According to another aspect of the present invention, the illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, and the eye is out of contact with the iris imaging apparatus.

According to another aspect of the present invention, the module further comprises at least a visible indicator or an audible indicator to indicate when the image of the iris has been obtained. According to another aspect of the present invention, the module further comprises a focus assessment processor coupled to the visible indicator and/or the audible indicator.

According to another aspect of the present invention, the processor unlocks a telephone responsive to a signal received from the central station.

In a further embodiment within the scope of the present invention, a method of unlocking a telephone responsive to the identification of a person comprises the steps of: (a) storing image information of the iris of at least one person's eye; (b) illuminating an eye of an unidentified person having an iris; (c) obtaining an image of the iris of the unidentified person; (d) determining if the image is an image of sufficient quality for a step (f) of comparing; (e) repeating steps (b) through (d) until the image of sufficient quality is obtained; (f) comparing a template of the obtained image with the stored image information to identify the unidentified person; and (g) unlocking the telephone responsive to a result of the step of comparing. The stored image information used for identification can be a code or template extracted from the image, and the comparison can be performed at a central database maintained by a telephone service provider.

According to one aspect of the present invention, the method further comprises the step of activating an indicator if the image is of insufficient quality. The indicator is an audible indicator.

According to another aspect of the present invention, the method further comprises the step of activating an indicator if the image is of sufficient quality. The indicator is a visible indicator.

According to another aspect of the present invention, the method further comprises the step of activating an indicator responsive to the step of comparing. The indicator is a visible indicator.

In accordance with a further aspect of the present invention, the step of determining if the image is an image of sufficient quality comprises the step of focus assessment processing the image.

According to another aspect of the present invention, the telephone is unlocked if the step of comparing identifies the person.

In a further embodiment within the scope of the present invention, a system of identification of a person for unlocking a telephone comprises a telephone security module, a second memory for storing at least one template of at least one image of an iris of at least one person's eye; and a second processor for comparing the template of the stored iris image with the at least one stored template of the second memory to identify the person, and for unlocking the telephone responsive to the result of the comparison.

In accordance with a further aspect of the present invention, the second memory and second processor are housed in a central station remote from the telephone security module.

In accordance with a further aspect of the present invention, the second processor unlocks the telephone when the template of the stored iris image substantially matches the at least one stored template of the second memory.

In a further embodiment within the scope of the present invention, a telephone security module comprises: iris acquisition means having a front surface for obtaining an image of an iris of an eye; a lens having a image plane disposed in front of the front surface of the iris acquisition means; a mirror disposed on a side of the lens opposite the iris acquisition means; an illuminator disposed along a side of the mirror; a first memory for storing at least one template of at least one image of an iris of at least one person's eye; a second memory for storing an iris image obtained by the iris acquisition means; a processor for extracting a template from the stored iris image; and a comparator for comparing the template from stored iris image with the at least one template to identify the person.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other aspects of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings. For the purpose of illustrating the invention, there is shown in the drawings an embodiment that is presently preferred, it being understood, however, that the invention is not limited to the specific methods and instrumentalities disclosed. In the drawings:

FIG. 1 is a schematic diagram of an exemplary iris imager in accordance with the present invention;

FIG. 2A is a schematic diagram of the imager of FIG. 1 shown in greater detail;

FIG. 2B is a schematic diagram of another exemplary imager in accordance with the present invention;

FIG. 3 is a simplified flowchart of a method of operation in accordance with the present invention;

FIG. 4 is a schematic diagram of an exemplary iris image recognition system in accordance with the present invention;

FIG. 5 is a schematic diagram of an exemplary iris imager having visual and aural indicators in accordance with the present invention;

FIG. 6 is a more detailed flow chart of a method of operation in accordance with the present invention;

FIG. 7 is a schematic diagram of an exemplary iris image recognition system having a focus assessment processor in accordance with the present invention;

FIG. 8 is a schematic diagram of an exemplary iris imager incorporated into a telephone in accordance with the present invention;

FIG. 9 is an isometric view of an exemplary telecommunications iris imager and telephone in accordance with the present invention; and

FIG. 10 is a flow diagram of an exemplary method of operation of a telecommunications iris imager in accordance with the present invention.

DESCRIPTION OF EXEMPLARY EMBODIMENTS AND BEST MODE

The present invention is directed to a compact, handheld imaging apparatus and method which can be used to capture high-quality iris images. Preferably, the imager has sensors and indicators which assist the human operator in aligning and focusing the device. The imager also automatically captures the image when proper positioning is achieved. Because it is small and compact, it is practical for integration into a cellular telephone where it is used to authenticate telephone subscribers and eliminate cellular telephone fraud. Throughout the following detailed description similar reference numbers refer to similar elements in the figures of the drawings.

FIG. 1 illustrates a preferred embodiment of the handheld imager 100 in accordance with the present invention. The exemplary handheld, non-invasive, non-contacting iris imager comprises iris acquisition means 105, an imaging lens 110, a mirror 120, an optional diopter correction lens 125, and an illuminator 130. The imager 100 is preferably powered by a standard DC supply provided by a cellular telephone.

The iris acquisition means 105 is preferably a conventional solid state video camera, such as a charged coupled device (CCD) or complementary metal oxide semiconductor (CMOS) device. A preferred camera is a 1/3 inch format, monochrome CCD board camera, such as Computar Model EM200. Preferably, the video camera 105 is sensitive to light of wavelengths in the range of about 400 nanometers to about 1100 nanometers, and is positioned so that its front surface coincides with the image plane of the lens 110 in front of it. In the preferred embodiment, the object plane of the lens is approximately 89 mm in front of the lens 110. More preferably, the lens 110 is an optical lens with approximately 14.2 mm focal length.

The mirror 120, preferably a concave cold mirror having a radius of curvature preferably about 276 mm, is disposed on the side of the lens 110 opposite the video camera 105 and creates a magnified virtual image of the iris behind the mirror 120. In the preferred embodiment, the mirror 120 reflects visible light with wavelengths in the range of about 400 to about 700 nanometers, and passes light having longer wavelengths, such as those in the range of about 700 to about 900 nanometers.

The illuminator 130 is positioned just outside the edge of the cold mirror 120 and is used to illuminate the iris of the subject being identified. The preferred illuminator 130 emits light having wavelengths of about 680 to about 900 nanometers. Preferably, the illuminator 130 is a miniature quartz halogen or krypton gas bulb operating at approximately 1 watt.

The imager acquires images of an iris with sufficient clarity, focus, and size for use with conventional image processing and comparison routines, preferably in less than about 3 seconds. A preferred image processing and comparison routine is described in U.S. Pat. No. 5,291,560, "Biometric Personal Identification System Based on Iris Analysis", issued to Daugman, and commonly assigned with the present invention to IrisScan Inc., and incorporated herein by reference. However, any processing and comparison technique can be used with the image that is acquired at the imager, such as the image pixel correlation technique

described in U.S. Pat. No. 5,572,596, "Automated, Non-Invasive Iris Recognition System and Method", issued to Wildes et al and the techniques described in U.S. Pat. No. 4,641,349, "Iris Recognition System", issued to Flom et al., both of which are incorporated herein by reference.

FIG. 2A shows the apparatus of FIG. 1 in greater detail. The lens 110 gives a high resolution image of the eye 150 of the user, who is positioned in front of the lens 110, so that extreme proximity between the eye 150 and the imager 100 is not required (i.e., no contact is needed between the subject and the imager 100).

The handheld iris imager comprises a solid-state image capture device and an optical system which forms an image 109 of the iris on the image capture device at the image plane of the video camera 105 and at the same time produces a virtual image 115 of the iris which the user can use to position and focus the iris image. As a result, the user can, using the same eye being imaged, see a reflected image of the iris which can be used to position the handheld imager 100 so that a good iris image (i.e., an image that can be processed and compared to those stored in a database) can be obtained.

FIG. 2A also shows an optional dioptric correction lens 125 positioned between the eye 150 and the cold mirror 120. The dioptric correction lens 125 is an adjustable optical element which corrects for the close-range focusing ability of the individual eye, which varies from subject to subject. When the lens 125 is properly adjusted, the magnified, reflected virtual image 115 of the subject's eye appears in sharp focus to the subject at the same eye-to-mirror distance at which the subject's eye is sharply focused on the front surface of the camera. This simplifies use of the imager, because the subject simply positions the image so that the virtual image 115 of the iris appears sharply focused.

A preferred embodiment of the dioptric correction mechanism has no correction lens 125 and instead has a mechanical means (not shown) for adjusting the position of the cold mirror 120 relative to the camera lens 110. This allows the user to vary the object distance of the cold mirror 120, thus changing the eye-to-lens distance at which the virtual image 115 of the iris is sharply focused.

The ability to set the dioptric correction mechanism to accommodate a particular user has a great utility if the imager is used by only one person most of the time. Once the correction is set, the user can easily position the device to obtain a sharply focused reflected image. This automatically produces a sharply focused image from the camera and substantially immediate acceptance of the image by the focus assessment processor described below. Image capture time is thereby reduced and overall convenience and utility is enhanced.

An eye 150 is positioned in front of the imager 100 (e.g., about 3.5 inches in front), as shown in FIG. 2A, and the illuminator 130 is turned on. This, in turn, illuminates the eye 150 and the iris therein. Preferably, the light having wavelengths of about 400 to about 700 nanometers is reflected by the cold mirror 120, thereby forming a magnified virtual image 115 behind the mirror 120 which the user can see through the eye being imaged. The radius of curvature of the mirror is selected so that the magnified image 115 of the eye substantially fills the user's entire field of view. Hence, when the imager 100 is positioned so that the entire eye 150 is visible, it is virtually assured that the eye 150 will be substantially centered in the object plane 140 of the camera 105. Under these conditions, the light having wavelengths of about 700 to about 900 nanometers is passed

by the mirror 120 and forms an approximately centered image 109 of the eye 150 at the image plane 107 of the camera 105. The image is then captured and processed, as described below.

Although a cold mirror (one which reflects shorter wavelengths and passes longer wavelengths) is described herein, it is understood that a hot mirror (one which reflects longer wavelengths and passes shorter wavelengths) could also be used in accordance with the present invention. Such a configuration is shown in an imager 101 in FIG. 2B. The eye 150 is illuminated by an illuminator 131 emitting light having wavelengths in the range of about 680 to 900 nanometers. This light is reflected by the eye 150 and the light having wavelengths in the range of about 700 to 900 nanometers is reflected by the hot mirror 121 to be focused by the lens 111 onto the front surface of the camera 106. Light reflected from the eye 150 having shorter (visible) wavelengths in the range of about 400 to 700 nanometers passes through the hot mirror 121 and strikes a concave broadband mirror 122 which reflects light having wavelength from about 400 to 900 nanometers. This light forms a virtual image 115 of the eye 150 behind the concave mirror 122 that the user can see and use to align and focus the device, as described below.

The imager 100 of FIGS. 1 and 2A, as well as the imager of FIG. 2B, is used in a system to identify the iris image that has been captured. As shown in FIG. 3, the eye is illuminated at step 160, and an acceptable or suitable image of the iris is obtained at step 165. The image is processed to extract an iris template or code at step 170, the template or code is encrypted (optional) and transmitted to the cellular provider (such as a central station; e.g., a Mobile Telephone Switching Office) at step 175, and the template or code is decrypted (if necessary) and compared to pre-existing templates or codes of authorized subscribers stored in a memory or database for identification and authorization of the user at step 180. If the user is authorized, the cellular provider enables the call placement at step 185. The cellular provider can either enable the call at the central station or send a signal to the telephone processor directing it to unlock the telephone.

FIG. 4 is a schematic diagram of an exemplary iris image recognition system in accordance with the present invention. The imager 100 is coupled to a microprocessor 210 that performs the processing and encryption. The microprocessor 210 resides in a cellular telephone 200.

The microprocessor 210 is coupled to the imager 100 via conventional cables and/or printed circuit boards (PCBs) that are incorporated into the telephone 200. Other conventional means for coupling the imager 100 and the microprocessor 210 can be employed. The microprocessor 210 controls the imager 100 and runs software held in read only memory (ROM) 205. The processor 210 is connected via a bus 207 to the ROM 205, a random access memory (RAM) 232, another memory such as an erasable programmable ROM (EPROM) 230, and an input/output (I/O) controller 225. The RAM 232 is large enough to hold at least one captured image of an iris. The I/O controller 225 is connected to the appropriate circuitry and drivers (not shown) for issuing commands to control the imager 100.

The imager 100 preferably uses a digital camera and transmits digital images directly to the processing unit 210. "On/off" data is transmitted from the imager 100 to the processor 210 to initiate the image acquisition function. A digital image could be provided if a digital camera is used.

The image processing consists of a number of image processing steps (such as those described in U.S. Pat. No.

5,291,560 and U.S. Pat. No. 5,572,596, which are herein incorporated by reference) which lead to extraction of a unique and highly specific digital biometric template that can be used to identify the individual based on intensity patterns within the iris. The biometric template is transmitted to the cellular provider where it is compared against other templates stored in a memory or database. The database stores selected data representing images of the iris of a plurality of subjects. A match of the biometric template with a template stored in the database identifies the subject whose iris is being imaged.

Although an image of the eye is reflected back to the subject in mirror 120, this may not provide the desired feedback to the user to enable the user to properly position the imager so that a suitable iris image is obtained. For example, a user may be a novice in using and positioning the imager 100 with respect to the eye 150, or the user may be attempting to image the eye of another subject with the imager. Thus, preferably, the imager 100 comprises a passive feedback mechanism to guide the user in positioning the eye 150 to an optimum location to allow acquisition of a suitable image.

The passive feedback mechanism is an indicator or combination of indicators that provides, on a near real-time basis, an indication to the user that an adequate iris image has or has not been obtained. FIG. 5 is a schematic diagram of an exemplary iris image recognition system that includes position indicators in accordance with the present invention. Preferably, the indicator is visible and/or audible, such as, for example, an indicator lamp 305 (e.g., a light emitting diode (LED)) that lights when an acceptable image has been captured (i.e., "image acquired"), and a aural indicator via a speaker 310, such as a beep or other tone, that sounds periodically until an acceptable image has been captured (i.e., "imaging in progress").

Additional indicators 306, 307 can be also be used, either alone or in combination, for such indications as "subject identified-accept" and "subject not identified-reject". These indications would be activated pursuant to the results of the processing and comparison performed at the database server at the cellular provider, as described above with respect to FIG. 3. Alternatively, other display devices, such as liquid crystal displays used for other purposes within the telephone, could be used as indicators.

The imager 100 also preferably has an on/off switch (not shown), such as a pushbutton, for powering up the imager and initiating the image acquisition process. Power for the imager 100 is preferably supplied by a battery. The imager 100 receives and acts on instructions from the processor 210 to perform functions such as lighting or turning off the indicator lamp(s) 305, providing the audible signals via the speaker 310, and lighting the 'accept' and 'reject' indicators.

FIG. 6 is a more detailed flow chart of a method of operation in accordance with the present invention. The eye is illuminated at step 350 and an image of the iris is obtained at step 355. At step 360, it is determined if the image is suitable for use with the image processing and comparison routines. If the image is suitable, the image is passed to the processor for further processing, at step 370, and transmission to the cellular provider. A comparison of the template to the templates stored in a database at the cellular provider is performed at step 373. If the comparison provides a positive match, then authorization is granted at step 376 for the user to use the phone. If the comparison does not provide a positive match, then authorization is not granted for the user to use the phone.

If the image is not suitable at step 360, then at step 380, the indicator(s) is activated (e.g., a beep sound is issued), and processing continues at step 355 (i.e., another image is obtained).

Because the eye's own focusing system automatically adjusts to bring the virtual image 115 into sharp focus to the user, it cannot be relied upon to always accurately focus the eye image on the camera 105. For this purpose, a focus assessment system is used in one embodiment, as shown in FIG. 7. Digital video image information from the imaging device 100 is stored in a frame buffer memory 410, such as a RAM similar to RAM 232 described above with respect to FIG. 4, and capable of storing one complete frame of digitized video information. A focus assessment processor 420 accesses the digitized image information and applies certain measurement algorithms which are disclosed in a co-pending application entitled "Video-Rate Focus Assessment", filed concurrently with this application Ser. No. 60,109,960 Nov. 25, 1998, and incorporated herein by reference. The output of the focus assessment is used to control an indicator, such as the audible indicator 310. As long as the focus assessment processor 420 determines that the captured image is not acceptable for further processing and comparison, the audible indicator 310 is directed to emit periodic sounds to alert the user. Images are repeatedly acquired and assessed until an acceptable one is received. After an acceptable iris image has been received, the audible indicator 310 is turned off and the final image is retained for further processing and comparison, for example, by the microprocessor 210, as described above.

Any known technique for image focusing can be used with the imager of the present invention, such as those described in U.S. Pat. No. 4,876,608, entitled "Focus and Signal to Noise Measurement Routines in Input Scanners", issued to Eaton, U.S. Pat. No. 5,151,583, entitled "Focus Adjustment Device Having Restricting Means for Restricting a Selecting Action According to the Degree of Nearness of a Distance Measurement", issued to Tokunaga et al., and U.S. Pat. No. 5,404,163, entitled "In-Focus Detection Method and Method and Apparatus Using the Same for Non Contact Displacement Measurement", issued to Kubo. The preferred system and method for focus assessment is described below.

A focus score is computed for each video frame (i.e., each captured image). If the focus score exceeds a predetermined value, then it is determined that the image is focused enough for further processing and comparison. If the focus score does not exceed the predetermined value, then it is determined that the image is not focused enough for further processing, and an indicator (such as indicator 310, described with respect to FIG. 5) is activated and a further image is captured. Alternatively, a sequence of image frames can be obtained that cycle through a range of focus distances strobed at the video frame-rate, and the focus score computed for each frame can enable the selection of the best focused frame within the sequence of frames. For example, by obtaining image frames at each of several different lens settings and then fitting a spline curve to their respective focus scores one can predict the lens position that would deliver substantially the sharpest focus, by setting the derivative of the parameterized spline curve to zero and then solving the equation for position.

Specific implementation features of the preferred focus assessment system and method which enable its real-time operation, include (1) the computation of quantities in the 2D Fourier domain, without needing to compute an actual 2D Fourier Transform of an image (this avoids the need for

approximately 2.25 million floating-point operations required for an FFT (Fast Fourier Transform) on a 500×500 pixel image, as the computational complexity of an FFT on $n \times n$ data is $O(n^2 \log_2 n)$; (2) only 6,400 integer multiplications (squarings) are performed, which in turn can be eliminated altogether by using small look-up tables; (3) no floating-point operations are required; (4) computation of focus scores is based upon simple algebraic combinations of pixel values within local closed neighborhoods, repeated across regions of the image; and (5) these operations not only allow the algorithm to execute in real-time, but it also enables a straightforward implementation in simple, low-cost, hardware devices that could be embedded within a digital camera or frame grabber.

Preferably, the focus assessment processor 420 is fast enough to determine a focus score for each frame in a video image stream in less than the time it takes to acquire a new frame (e.g., approximately 25 ms). The frame-by-frame focus scores can be used to control a moving lens element for rapid and accurate focus control, or alternatively, to select which of several frames in a video stream is the one in best focus. The rapid selection of well-focused video frames for further processing, such as image analysis and pattern recognition, is important in real-time computer vision because it prevents wasting processing time on poorly-focused images.

The preferred focus assessment processor measures the focus quality of video images at standard rates of 25 (PAL) or 30 (NTSC) frames per second.

It is contemplated that the focus assessment processor 420 can be implemented in a general purpose personal computer (PC) or by a dedicated, low cost processor which is small enough to be incorporated into the camera electronics.

The processing of a video frame results in the return of an integer value (on a scale between 0 and 100) reflecting the quality of focus; the larger the value of the integer, the better the focus. A value of 0 indicates a completely defocused image whereas the value of 100 indicates maximum focus quality. A predetermined threshold is used to determine whether an image is sufficiently focused or whether another image needs to be retrieved. For example, values greater than about 40 can indicate sufficient quality of focus to warrant further image processing, while values less than about 40 cause a new image frame to be grabbed, and optional feedback provided to the focusing mechanism, if one exists, or to the subject controlling the camera position (via the indicator 310, for example).

Optical defocus is a phenomenon of the 2D Fourier domain. An image represented as a 2D function of the real plane, $I(x, y)$, has a 2D Fourier Transform $F(\mu, v)$ defocused as shown in equation 1.

$$F(\mu, v) = \frac{1}{(2\pi)^2} \iint_{x,y} I(x, y) e^{i(\mu x + v y)} dx dy \quad (1)$$

In the image domain, defocus is preferably represented as convolution by the 2D point-spread function of the defocused optics. This in turn may be modeled as a Gaussian whose space constant is proportional to the degree of defocus. Thus, for perfectly focused optics, the optical point-spread function shrinks almost to a delta function, and convolution with a delta function causes no change to the image. Progressively defocused optics equates to convolving with a wider and wider point-spread function, which averages together whole neighborhoods of pixels by such a weighting function, thereby producing an increasingly blurred image.

If the convolving optical point-spread function causing defocus is modeled as a Gaussian whose width represents the degree of defocus, then defocus is equivalent to multiplying the 2D Fourier Transform of a perfectly focused image with the 2D Fourier Transform of the "defocusing" (convolving) Gaussian. This latter quantity is itself just another 2D Gaussian but in the Fourier domain, and its space constant (σ) there is the reciprocal of that of the image-domain convolving Gaussian that represented the optical point-spread function. The preferred focus assessment processor uses (1) the duality of convolution and multiplication in the two domains; (2) the fact that a Gaussian has a Fourier Transform which is itself a Gaussian, but with the reciprocal width because of (3) the Similarity Theorem. Thus, the 2D Fourier Transform $D_\sigma(\mu, v)$ of an image defocused to degree σ is related to $F(\mu, v)$, the 2D Fourier Transform of the corresponding in-focus image, as given by equation 2.

$$D_\sigma(\mu, v) = e^{-\frac{(\mu^2 + v^2)}{\sigma^2}} F(\mu, v) \quad (2)$$

From the above equation, the effect of defocus is to attenuate primarily the highest frequencies in the image, and that lower frequency components are virtually unaffected by defocus since the exponential term approaches unity as the frequencies (μ, v) become small. For simplicity, the present description has assumed isotropic optics and isotropic blur, and the optical point-spread function has been described as a Gaussian. However, the analysis can readily be generalized to non-Gaussian and to anisotropic optical point-spread functions.

Thus, an effective way to estimate the quality of focus of an image is to measure its total amount of energy in the 2D Fourier domain at high spatial frequencies, since these are the most attenuated by defocus. One may also perform a kind of "contrast normalization" to make such a spectrally-based focus measure independent of image content, by comparing the ratio of energy in the highest frequency bands to that in slightly lower frequency bands. Such spectrally-based energy measurements are facilitated by exploiting Lord Rayleigh's theorem for conserved total power in the two domains, shown in equation 3.

$$\iint_{-\infty}^{+\infty} \iint_{-\infty}^{+\infty} |I(x, y)|^2 dx dy = \iint_{-\infty}^{+\infty} \iint_{-\infty}^{+\infty} |F(\mu, v)|^2 d\mu d\nu \quad (3)$$

Thus, high-pass filtering or band-pass filtering an image at a ring of high spatial frequency (using only convolution in the 2D image domain) and measuring the residual energy, is equivalent to making the corresponding energy measurement in the high frequency bands of the 2D Fourier domain. The appropriate measurements in the 2D Fourier domain to assess focus can be performed without computing a time-consuming 2D Fourier Transform. Indeed, the measurements can be performed without even a single floating-point operation, and even without any multiplications if appropriate convolution kernels and look-up tables are used.

A real-time procedure for focus assessment based on these theoretical principles is used in the focus assessment processor 420. It executes much faster than the video frame-rate, and so real-time focus assessments can be made on a frame-by-frame basis. These can be used either to control the position of a focusing lens element, or alternatively as a type of autofocus system in which frames are grabbed at a variety of focal depths in order to select only the best one for processing, or to prevent time being wasted on processing image frames which are assessed to be in poor focus.

The 2D spectral measurements described above can be implemented by convolving an image with the following convolution kernel, in which pixel values within a predetermined region, such as, for example, an (8×8) neighborhood, are added together with the weights indicated in each of the cells:

-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	+3	+3	+3	+3	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1

It should be noted that no pixel-by-pixel multiplications are needed in order to impose these weights. Rather, the pixels in the central region are added together, such as the (4×4) square, that sum is tripled, and then all pixel values in the outer two pairs of rows and columns are subtracted from the tripled sum. The result is squared and added to an accumulator, thus implementing the left-hand side of equation (3) above for this local region of the image. The complete (8×8) convolution kernel is then moved to a new position in the image, along a sampling grid that selects every 4th row and every 4th column, and the operation is repeated. Thus, to assess the quality of focus within the central (320×320) region of an image, this set of 64 pixel summations followed by a squaring operation is repeated a total of $(320/4)^2=6,400$ times.

In the 2D Fourier domain, the spectral consequences of this operation can be appreciated by examining the 2D Fourier Transform of the convolution kernel above. The kernel is equivalent to the superposition of two centered square box functions, one of size (8×8) and amplitude -1, and the other of size (4×4) and amplitude +4 (for the central region in which they overlap, the two therefore sum to +3). The 2D Fourier Transform of each of these square functions is a 2D "sinc" function, whose size parameters differ by a factor of two in each of the dimensions and whose amplitudes are equal but opposite, because the two component boxes have equal but opposite volumes. Thus, the overall kernel has a 2D Fourier Transform $K(\mu, v)$ which is the difference of two differently-sized 2D sinc functions, as given by equation 4.

$$K(\mu, v) = \frac{\sin(\mu)\sin(v)}{\pi^2\mu v} - \frac{\sin(2\mu)\sin(2v)}{4\pi^2\mu v} \quad (4)$$

This is a high-pass (or ultimately a band-pass) filter, selecting only a high range of spatial frequencies in all orientations. Towards its center, corresponding to very low spatial frequencies, its value approaches zero (as can also be inferred from the fact that the sum of all pixel weights in the convolution kernel shown above is zero). Thus, low frequencies play little or no role in computing a focus score, and only relatively high frequencies contribute significantly to the computation of a focus score. Equation (3) shows that summing the squares of all the local convolution sums across the image is equivalent to summing the total amount of high frequency energy in the 2D Fourier Transform of the image. The action of the convolution kernel is to impose the above power spectral weighting function so that primarily high frequency energy is measured.

Finally, the summated 2D spectral energy is passed through a compressive nonlinearity of the form $f(x)=100$

$x^2/(x^2+c^2)$ in order to generate a normalized focus score in the range of 0 to 100 for any image.

The focus assessment technique is applied immediately after each image frame is digitized and stored in the frame buffer memory 410 in order to assess whether the focus quality is sufficient to warrant any further processing. If the calculated focus quality value of the captured image is greater than or equal to a predetermined value, the image is passed to applicable programs for further processing, for example for extraction of a biometric template. The focus assessment technique can be used to compare the relative focus of an entire series of images in order to select the one most in-focus (i.e. having the highest focus assessment score), as well as to measure a single image.

15 The focus assessment technique can be used to provide a feedback indication to a system user who controls the position of the imager relative to the object being imaged. This can be accomplished by activating an indicator which would continue, while successive images are captured and 20 their focus assessed, until the focus assessment score exceeds a predetermined value. At this point, the indicator is deactivated and the last image captured is transferred to the image processor 210 where it is processed to extract the biometric template.

25 The application of the focus assessment technique in combination with the feedback indicator helps resolve the man-machine interface problems associated with the use of digital imaging devices on the eye. Individuals using the system are provided positive, objective indicators and feedback as to the quality of image focus. The focus assessment processor can also be used in any situation where it is required to determine the quality of focus of video images at industry standard frame rates (NTSC and PAL).

Thus, the image is obtained at the imager and transmitted 35 to an analog to digital converter 405. The digitized video information is then stored in a frame buffer memory 410. The focus assessment processor 420 isolates the central 320×320 region of the image. 8×8 pixel blocks (each pixel is in only one block) are then processed by first summing 40 pixels in the central 4×4 region, tripling that sum, and then subtracting from this value all the pixel values in the outer two pairs of rows and columns. This result is then squared. This process is performed on each 8×8 block, and the results are summed. After the entire image has been processed, the 45 summed result is compressed nonlinearly to generate a focus score between 0 and 100. This score is then compared to a predetermined number for determining if the indicator 310 should be activated.

The focus assessment is preferably performed by the 50 microprocessor 210, or it can be a separate processor element within the telephone.

It is contemplated that in addition to the focus assessment processor, an auto-focus lens system could be used in the present invention. The results of the focus assessment control the lens system, thereby automatically adjusting focus to produce an optimal image. This would place less of a premium on the accuracy with which the user positions the eye, and would be helpful if the user could not see or hear the indicators described above.

60 The iris imager of the present invention can be used as a security module for electronic devices such as a telephone. FIG. 8 is a schematic diagram of an exemplary iris imager incorporated into a telephone in accordance with the present invention. The imager 700 comprises the camera 105, lens 110, mirror 120, and illuminator 130, as described above with respect to FIG. 1. The imager 700 also comprises visible indicators 555, 556, 557, which are similar to indi-

cators 305, 306, 307, respectively, described above with respect to FIG. 5. An audible indicator 560, similar to indicator 310, is also disposed within the imager 700. The imager 700 further comprises electronics and circuitry 500 for processing and comparing the obtained image. The electronics and circuitry 500 comprises a microprocessor 510 (similar to microprocessor 210) that controls the imager 700 along with an I/O controller 525 and runs software held in a ROM 505. The processor 510 is connected to the ROM 505, a RAM 532 that is capable of storing at least one captured image or an iris, another memory 530, such as an EPROM, for storing a plurality of biometric templates or iris images that are to be compared with the captured iris image. The electronics and circuitry 500 is also connected to the camera 105, the illuminator 130, and the indicators 555, 556, 557, 560 for controlling these elements of the imager 700. The processor can also comprise a focus assessment processor, similar to the focus assessment processor 420.

It should be noted that in the embodiment of FIG. 8, the database memory 530 of templates is stored within the imager 700 and not at a central station (as described, for example, with respect to FIG. 4), as is the processor 510 used in the comparison. In the embodiment of FIG. 8, the comparison of the captured image template with the stored templates takes place locally within the telephone, and no data is sent to the central station for comparison or authentication.

The imager 700 is coupled to telephone electronics 570 for transmitting encrypted or unencrypted data to another telephone or system via an antenna. The telephone electronics 570 is essentially a telephone and is preferably a conventional cell phone having telephone electronics and is connected to a transmission antenna. Preferably, a conventional voltage regulator (not shown) provides the appropriate operating voltage to the imager 700 from the power supply (e.g., a battery) of the phone.

Preferably, the imager 700 of the present invention is incorporated into a handset of a telephone 575, as shown in FIG. 9. The present invention can be incorporated into a conventional digital cell phone, as shown in FIG. 9, such as those manufactured by Qualcomm.

FIG. 10 is a flow diagram of an exemplary method of operation of a telecommunications iris imager in accordance with the present invention. A user desiring to make a telephone call first unlocks the telephone by having his iris identified by the imager residing within the phone. The eye, and thus the iris, is illuminated at step 605. An image is obtained of the iris at step 610. At step 615, it is determined if the image is suitable for further processing and comparison, as described above. If the image is not suitable, the appropriate indicators are activated at step 620, and processing returns to step 610 with the capture of another iris image.

If the captured image is suitable for further processing, the image is processed at step 630 (an indicator can be activated to alert the user that a suitable image has been captured) and is compared to the stored images residing in a database, for example, in a memory, at step 635. If there is no match between the captured image and the stored images, at step 640, the appropriate indicators are activated at step 645, and the imaging routine exits. In this manner, the telephone remains locked, and cannot be used because it is determined that the user is unauthorized.

If there is a match between the captured image and the stored images, at step 640, the phone is unlocked (and an indicator can be activated) at step 650, and the user is then able to use the phone to place a call, for example. The phone

can be returned to its locked, secure state either upon being powered down or upon completion of the phone call.

Although illustrated and described herein with reference to certain specific embodiments, it will be understood by those skilled in the art that the invention is not limited to the embodiments specifically disclosed herein. Those skilled in the art also will appreciate that many other variations of the specific embodiments described herein are intended to be within the scope of the invention as defined by the following claims.

What is claimed is:

1. A telephone security module comprising:
iris acquisition means having a front surface for obtaining an image of an iris of an eye;

a lens having a image plane disposed in front of said front surface of said iris acquisition means;

a mirror disposed on a side of said lens opposite said iris acquisition means;

an illuminator disposed along a side of said mirror;

a memory for storing an iris image obtained by said iris acquisition means;

a processor for extracting a template from said stored iris image; and

a communications interface for transmitting said template to a central station.

2. The telephone security module according to claim 1, wherein said iris acquisition means comprises a camera, and said mirror is a cold mirror.

3. The telephone security module according to claim 2, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

4. The telephone security module according to claim 2, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

5. The telephone security module according to claim 1, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

6. The telephone security module according to claim 1, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

7. The telephone security module according to claim 6, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

8. The telephone security module according to claim 1, wherein said processor unlocks a telephone responsive a signal received from said central station.

9. A system of identification of a person for unlocking a telephone, comprising:

the telephone security module of claim 1;

a second memory for storing at least one template of at least one image of an iris of at least one person's eye; and

a second processor for comparing said template of said stored iris image with said at least one stored template of said second memory to identify the person, and for unlocking the telephone responsive to the result of said comparison.

10. The system according to claim 9, wherein said second memory and said second processor are housed in a central station remote from the telephone security module.

11. The system according to claim 9, wherein said second processor unlocks the telephone when said template of said stored iris image substantially matches said at least one stored template of said second memory.

12. A telephone security module comprising:

iris acquisition means having a front surface for obtaining an image of an iris of an eye;
a lens having a image plane disposed in front of said front surface of said iris acquisition means;
a mirror disposed on a side of said lens opposite said iris acquisition means;
an illuminator disposed along a side of said mirror;
a first memory for storing at least one template of at least one image of an iris of at least one person's eye;
a second memory for storing an iris image obtained by said iris acquisition means;
a processor for extracting a template from said stored iris image; and
a comparator for comparing said template from stored iris image with said at least one template to identify the person.

13. The telephone security module according to claim 12, wherein said iris acquisition means comprises a camera, and said mirror is a cold mirror.

14. The telephone security module according to claim 13, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

15. The telephone security module according to claim 13, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

16. The telephone security module according to claim 12, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

17. The telephone security module according to claim 12, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

18. The telephone security module according to claim 17, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

19. The telephone security module according to claim 12, wherein said processor unlocks a telephone responsive to the results of said comparison.

20. A telephone security module comprising:

a camera having a front surface for obtaining an image of an iris of an eye;
a lens having a image plane disposed in front of said front surface of said camera;
a concave cold mirror disposed on a side of said lens opposite said camera;
an illuminator disposed along a side of said mirror;
a memory for storing an iris image obtained by said camera;
a processor for extracting a template from said stored iris image; and
a communications interface for transmitting said template to a central station.

21. The telephone security module according to claim 20, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

22. The telephone security module according to claim 20, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

23. The telephone security module according to claim 20, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

24. The telephone security module according to claim 20, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

25. The telephone security module according to claim 24, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

26. The telephone security module according to claim 20, wherein said processor unlocks a telephone responsive a signal received from said central station.

27. A telephone security module comprising:
a camera having a front surface for obtaining an image of an iris of an eye;
a lens having a image plane disposed in front of said front surface of said camera;
a concave cold mirror disposed on a side of said lens opposite said camera;
an illuminator disposed along a side of said mirror;
a first memory for storing at least one template of at least one image of an iris of at least one person's eye;
a second memory for storing an iris image obtained by said camera;
a processor for extracting a template from said stored iris image; and
a comparator for comparing said template from stored iris image with said at least one template to identify the person.

28. The telephone security module according to claim 27, wherein said camera is sensitive to light having a wavelength in a range between about 400 nm and about 1100 nm.

29. The telephone security module according to claim 27, wherein said mirror reflects light having a wavelength in a range between about 400 nm and about 700 nm and passes light having a wavelength greater than about 700 nm.

30. The telephone security module according to claim 27, wherein said illuminator emits light having a wavelength in a range between about 680 nm and about 900 nm towards the iris of the eye being imaged, the eye being out of contact with the iris imaging apparatus.

31. The telephone security module according to claim 27, further comprising at least one of a visible indicator and an audible indicator to indicate when the image of the iris has been obtained.

32. The telephone security module according to claim 31, further comprising a focus assessment processor coupled to said at least one of a visible indicator and an audible indicator.

33. The telephone security module according to claim 27, wherein said processor unlocks a telephone responsive to the results of said comparison.

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US006038333A

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United States Patent [19]**Wang**

[11] **Patent Number:** **6,038,333**
 [45] **Date of Patent:** ***Mar. 14, 2000**

[54] PERSON IDENTIFIER AND MANAGEMENT SYSTEM**[75] Inventor:** **John Y. A. Wang, Mountain View, Calif.****[73] Assignee:** **Hewlett-Packard Company, Palo Alto, Calif.**

[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

[21] Appl. No.: **09/039,990****[22] Filed:** **Mar. 16, 1998****[51] Int. Cl.:** ~~7~~ **G06K 9/00****[52] U.S. Cl.:** **382/118; 382/313**

[58] Field of Search: **382/115, 116, 382/118, 313, 321, 324, 124, 125, 126, 127; 707/6, 9; 348/150, 151, 156, 158; 356/71; 395/186; 340/825.34**

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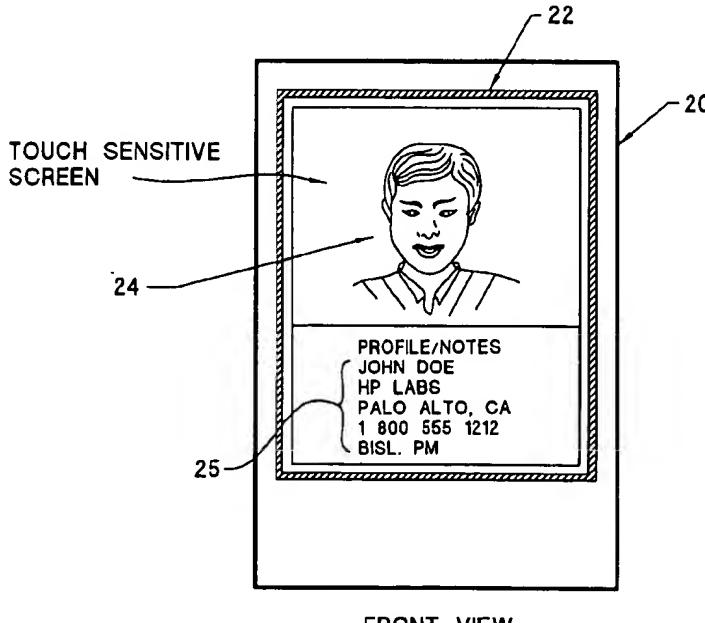
Primary Examiner—Leo H. Boudreau

Assistant Examiner—Brian P. Werner

Attorney, Agent, or Firm—Thomas X. Li

[57]**ABSTRACT**

A person identifier and management system is described. The person identifier and management system includes a face image database that stores the face feature data of each of a number of face images and the person-identifying data associated with each of the face images. A camera is also included in the person identifier and management system for capturing an input face image. A face analysis system is then coupled to the camera and the image database to extract the face feature data of the input face image and to compare the face feature data of the input face image with that of each of the face images stored in the database such that the person-identifying data of any stored face image similar to the input face image can be retrieved from the image database. A method of retrieving person-identifying information of an input face image from a face image database is also described.

7 Claims, 7 Drawing Sheets

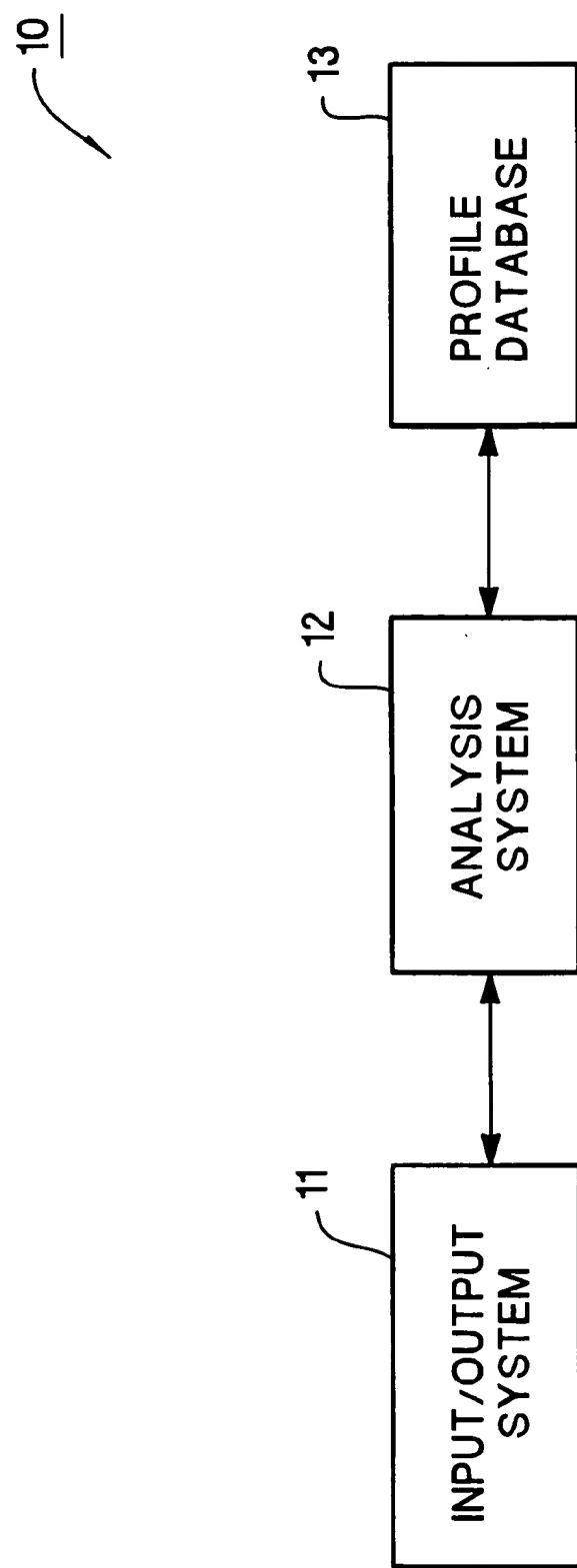


Figure 1

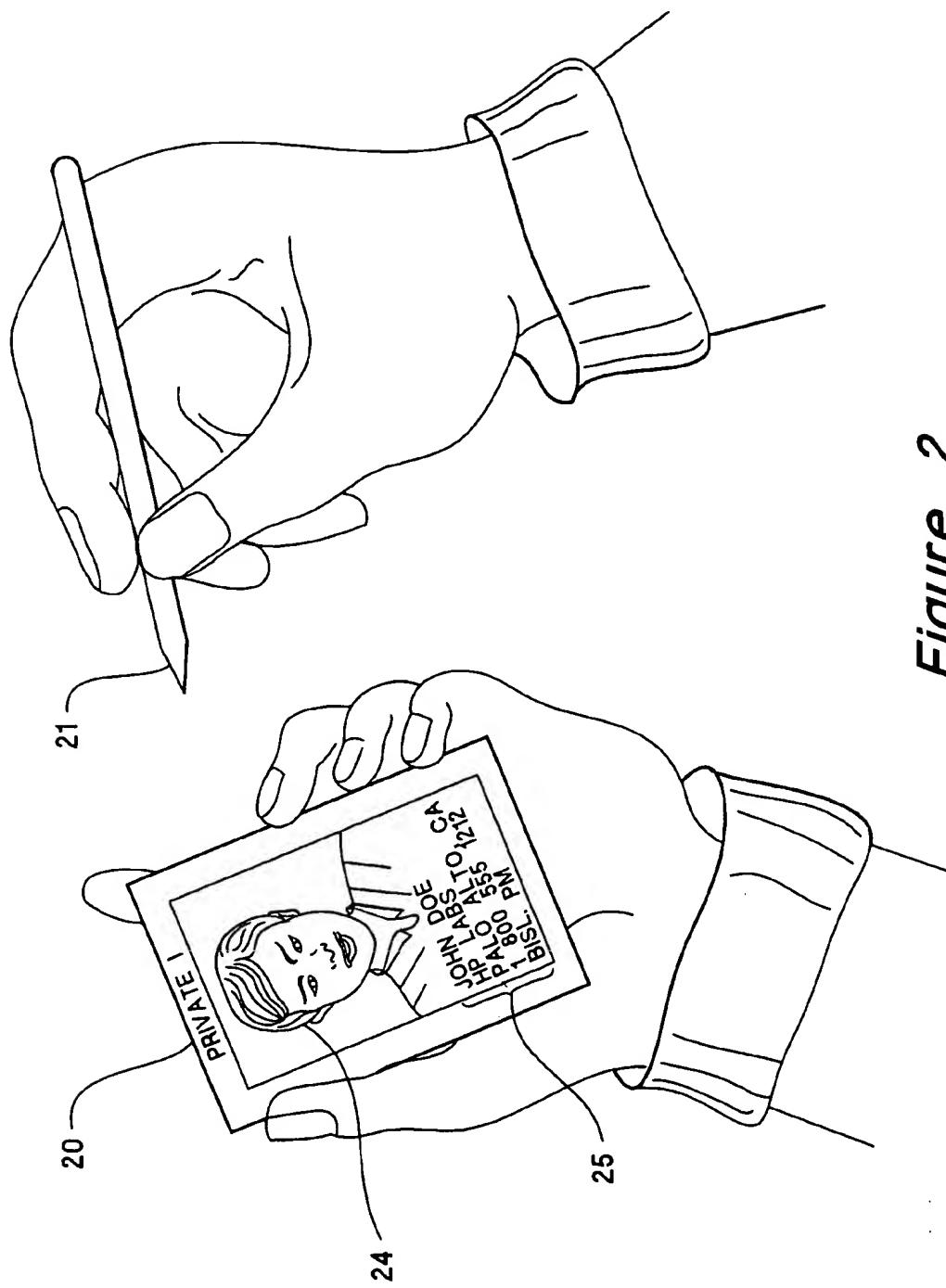
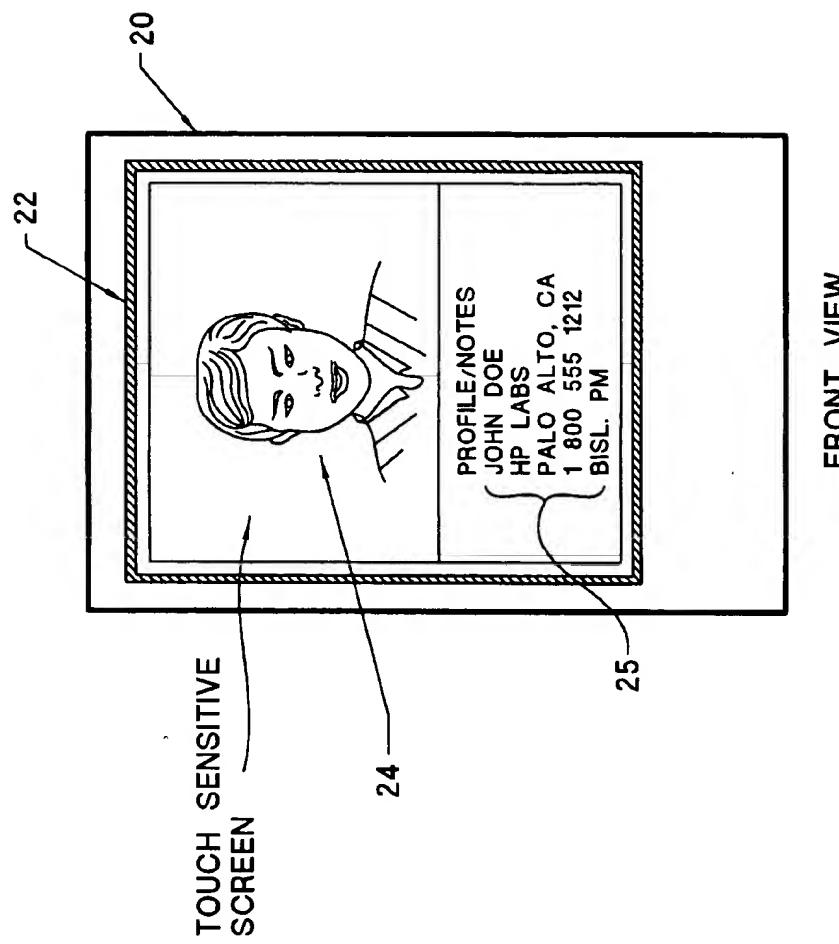


Figure 2



FRONT VIEW

Figure 3A

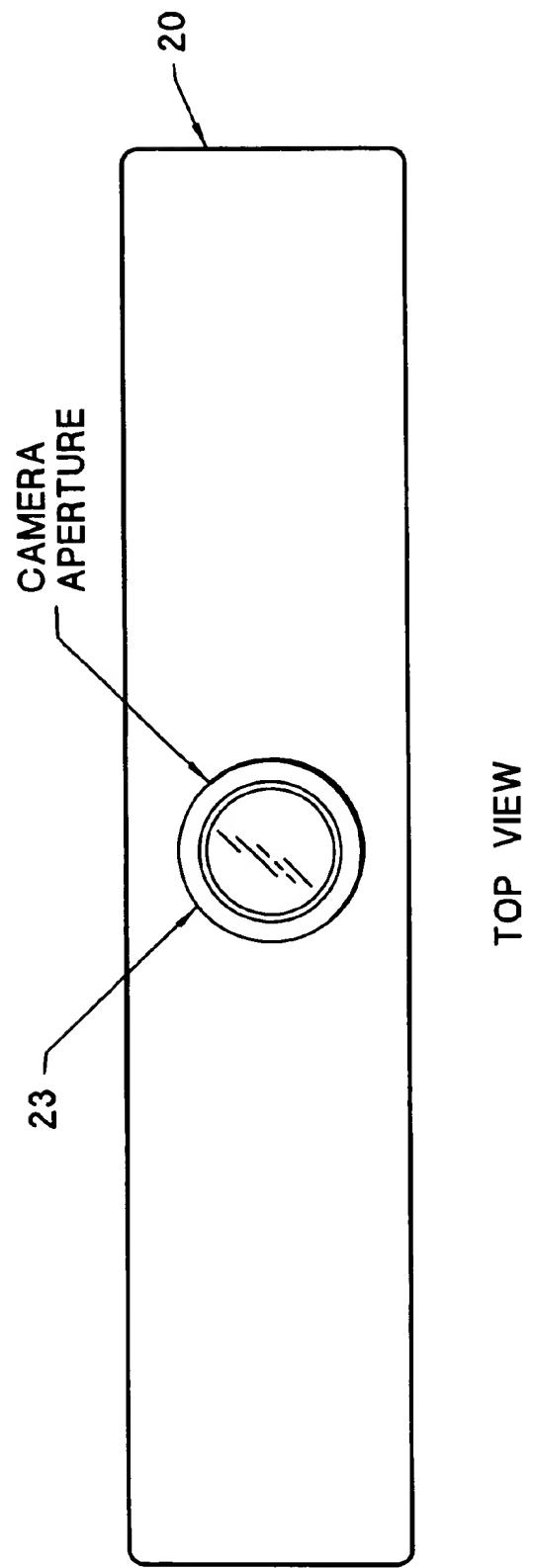


Figure 3B

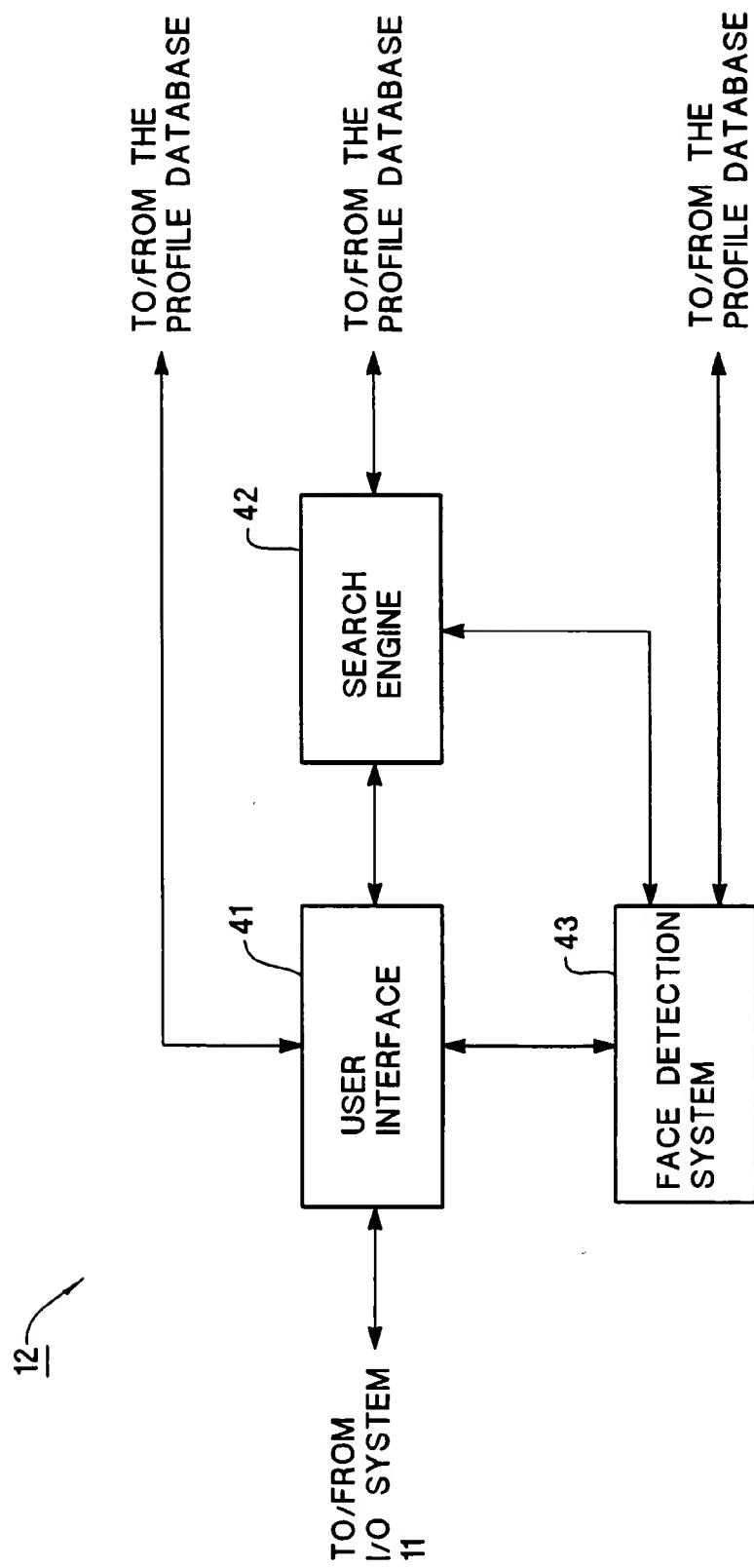


Figure 4

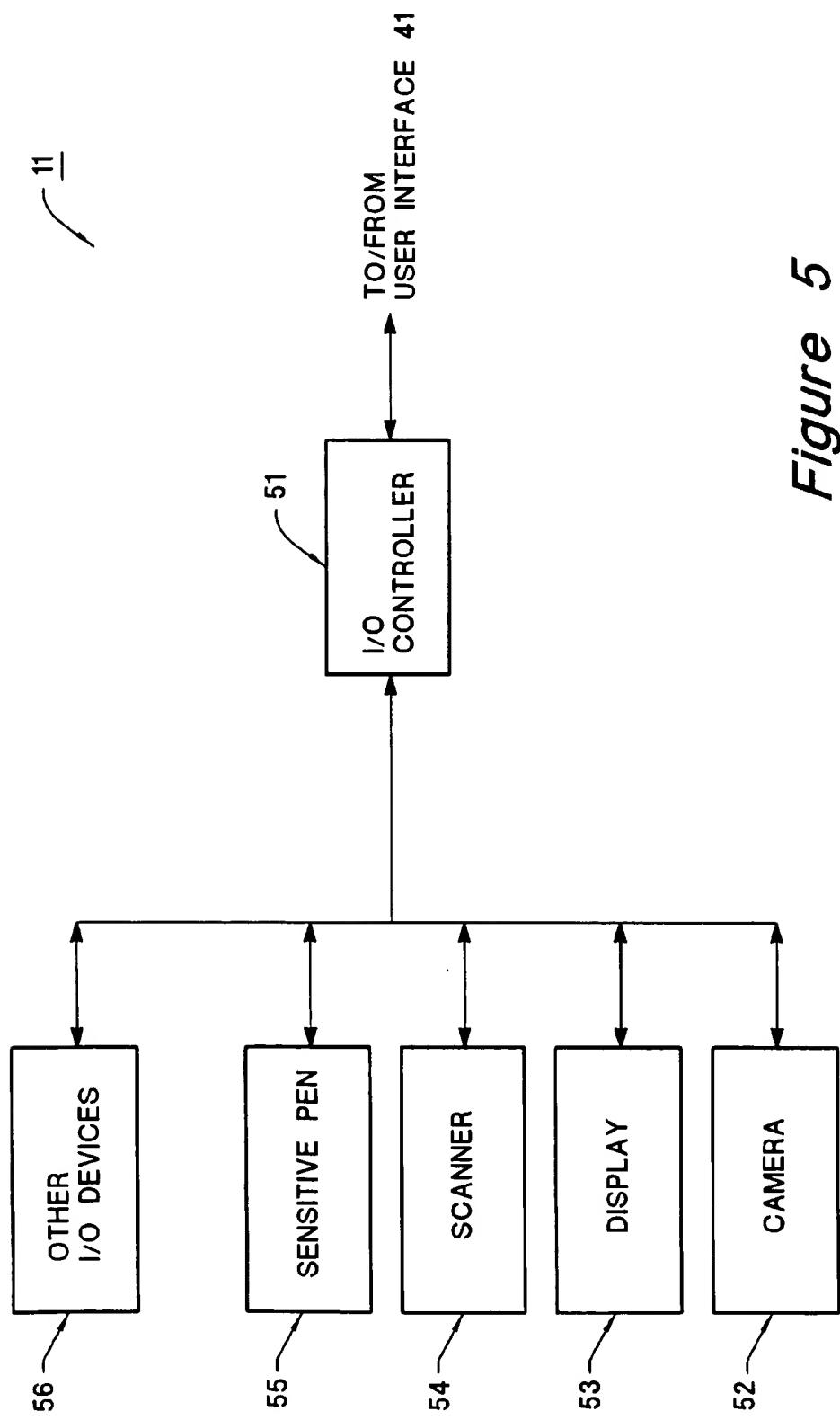
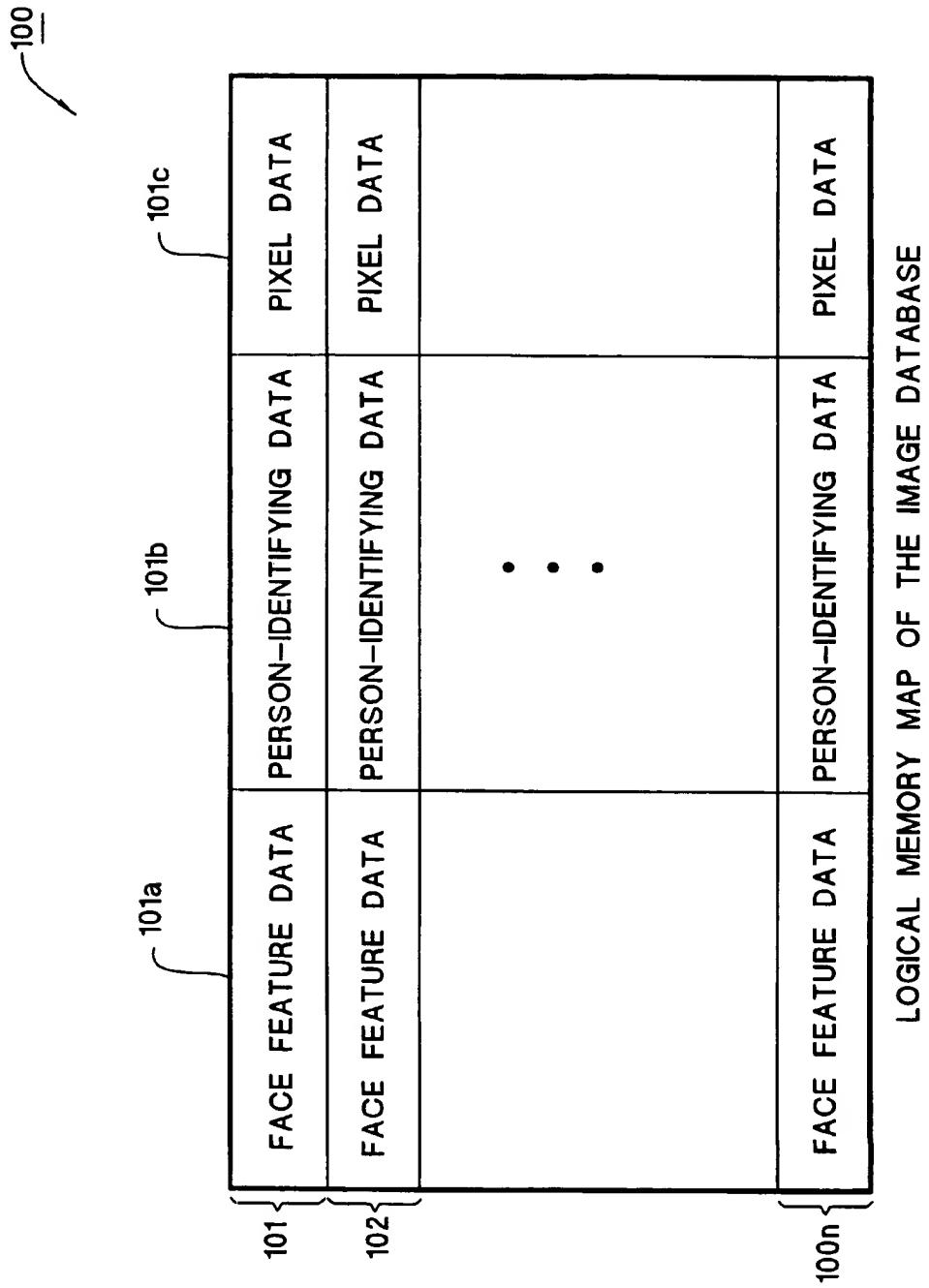


Figure 5

*Figure 6*

**PERSON IDENTIFIER AND MANAGEMENT
SYSTEM**

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention pertains to image processing and information management. More particularly, this invention relates to a person identifier and management system that can retrieve person-identifying information from a database based on an input face such that the input face can be identified.

2. Description of the Related Art

As is known, human nature typically shows that people want to be recognized by others. Thus, it is important for people to recognize and recall the names of other people they have previously met or acquainted during meetings, social functions, or other occasions. Not recognizing the person before you may affect you adversely. For example, if a superior or employer does not recognize or cannot recall the name of an inferior or employee, it may give the inferior/employee the impression that the supervisor/employer does not care about the inferior/employee, or the inferior/employee is not important in the organization. In addition, if a business person cannot recognize or recall the name of a business counterpart from another organization, it may affect the business dealing or potential business dealing with the organization that business counterpart represents.

However, for people who have a relatively large number of casual acquaintances, association of faces with names is a difficult memory game. In addition, some people are just not good at recognizing or recalling names of formal acquaintances, especially when the formal acquaintances have only been briefly introduced to you. Change of environment may also cause problems for people to recognize or recall names of others. For example, a person will have more difficulty in recognizing people initially if the person is surrounded by a large number of strangers (e.g., in a new office building).

With the advance of computer and image processing technologies, it is now possible to store an image in a computer system. This can be done using a digital camera to capture an image. In addition, a scanner can be used to convert a printed image into digital form. The digital image includes image pixels (or dots) arranged in a matrix. The data for each image pixel are then stored in the computer. The digital image can be retrieved for display from the computer.

This allows a face image database to be built in a computer system that can help the user to manage the acquaintances' information. The face image database typically stores a number of face images and the person-identifying information associated with each of the stored images. The person-identifying information is typically a text information that identifies the face. The person-identifying information in text format may include name, contact information, date and occasion of last meeting or all the prior meetings. When the user retrieves a face image from the database, the person-identifying information associated with that image is also retrieved from the database. When the person-identifying information is displayed with the associated face image, the user can then recognize the face and recall the name of the face.

However, searches within this face image database is still nearly impossible. In order to identify a desired face image stored in the computer based on an input face image, the

prior art typically causes the computer to compare the image pixel data of the input face image with the corresponding pixel data of each of the images stored in the computer. The comparison typically takes a very long time to complete and uses a lot of system resources (e.g., memory and communication bandwidth). This is because the computer has to compare each image pixel data of the input face image with the corresponding image pixel data of each of the stored face images. A match occurs when each pixel data of the input face image is similar the corresponding pixel data of a stored face image. Using this method, unless the two compared images are extremely similar, it is very difficult to find a match between any two face images. This is especially true because noise and other positional errors may be introduced into the image data when the input face image is captured.

SUMMARY OF THE INVENTION

One feature of the present invention is to help a user recall or recognize people the user has previously met.

Another feature of the present invention is to allow retrieval of personal-identifying information from a database in accordance with an input face image.

A farther feature of the present invention is to provide a person identifier and management system that searches for similar faces of an input face in a face image database such that person-identifying information associated with the similar faces can be retrieved from the database to identify the input face.

A still further feature of the present invention is to provide a personal person identifier and management system that is portable, personal, and easy to use.

A person identifier and management system is described. The person identifier and management system includes an image database that stores face feature data of each of a number of face images and person-identifying data associated with each of the face images. An image capturing system is also included for capturing an input face image. A face analysis system is then coupled to the image capturing system and the image database to locate and retrieve the person-identifying data of any stored face image similar to the input face image from the image database. The face analysis system does this by, for example, extracting the face feature data of the input face image and comparing the face feature data of the input face image with that of each of the face images stored in the database.

A method of retrieving person-identifying information from a face image database based on an input face image includes the step of extracting face feature data from the input face image. The face feature data of the input face image is then compared with that of a number of face images stored in the database. Each of the stored face images includes the person-identifying information that identifies the respective face image. If the face feature data of one of the stored face images matches that of the input face image, then the person-identifying information of that stored face image is retrieved from the image database to identify the input face image.

Other features and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the structure of a person identifier and management system that implements one embodiment of the present invention.

FIG. 2 illustrates the perspective view of the person identifier and management system of FIG. 1 as a portable, personal, and hand-held system in accordance with one embodiment of the present invention.

FIG. 3A is a front view of the personal person identifier and management system of FIG. 2.

FIG. 3B shows the top view of the personal person identifier and management system of FIG. 2.

FIG. 4 shows the analysis system of the person identifier and management system of FIG. 1.

FIG. 5 shows the input/output system of the person identifier and management system of FIG. 1.

FIG. 6 shows the data format for each of the face images stored in the profile database of the person identifier and management system of FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a person identifier and management system 10 that implements one embodiment of the present invention. As will be described in more detail below, the person identifier and management system 10 allows a user to retrieve person-identifying or face-identifying information of a person from a profile database (or face image database) 13 of the person identifier and management system 10 based on the person's face inputted to the person identifier and management system 10 such that the person can be identified or recognized by the user of the person identifying system 10. This means that the person identifier and management system 10 can use the input face image to search the profile database 13 for matching face or faces and their associated face-identifying or person-identifying data so that the input face can be identified or recognized.

As will be described in more detail below, the person identifier and management system 10 includes the profile database 13. The profile database 13 stores a number of face images and their associated face-identifying or person-identifying data. The profile database 13 stores the pixel data of each of the face images. In addition, the profile database 13 also stores the face feature data of each of the face images. The face feature data of a face image is associated with that face image in the profile database 13. The person-identifying data of each of the face images is also associated with the respective face image in the profile database 13.

In addition to the profile database 13, the person identifier and management system 10 also includes an analysis system 12 that (1) detects if an input image of the person identifier and management system 10 contains a face and (2) extracts the face feature data from the input image if the input image is detected to contain a face. The input image is supplied by an input/output system 11 connected to the analysis system 12. The input/output system 11 is also used for outputting the person-identifying data retrieved from the profile database 13.

The analysis system 12 accesses the profile database 13 with the extracted face feature data of the input face image to locate the matching face feature data in the profile database 13. When there is a match between the face feature data of the input face image and the face feature data of one or more stored face images, the person-identifying data of the matching face images are retrieved from the profile database 13. This allows the user of the person identifier and management system 10 to identify or recognize the input face image. The person identifier and management system 10 will be described in more detail below, also in conjunction with FIGS. 1-6.

FIG. 1 shows in block diagram form the structure of the person identifier and management system 10. The person identifier and management system 10 can be a single stand-alone device or implemented in a computer or computer-enabled system. If the person identifier and management system 10 is implemented in a computer system, the computer system can be a personal computer, a notebook computer, a mini-computer, a hand-held computer, a personal communicator, a workstation, a network computer, a server computer, or a mainframe computer.

As can be seen from FIG. 1, the person identifier and management system 10 includes the input/output system 11, the analysis system 12, and the profile database 13. The input/output system 11 is connected to the analysis system 12. The analysis system 12 is then connected to the profile database 13. The input/output system 11 is used to provide the input and output functions for the person identifier and management system 10. The analysis system 12 is used to detect a face from an input image and to use the face feature data extracted from the input face image to search the profile database 13 in order to identify the input face image.

The profile database 13 stores a number of face images and their face feature data and person-identifying or face-identifying data. The face feature data and the person-identifying data are fully searchable in the database 13. The face feature data and its creation will be described in more detail below, also in conjunction with FIGS. 1 and 4. The person-identifying data can be a text data, an image data, and a combination of text and image data. The person-identifying data of a face image may include the name of the person, affiliation or employment of the person, and time and occasion of last meeting or all of the previous meetings with the person. The employment information may include name of the company the person is currently working for, the title and position of the person within the company. In addition, the person-identifying data may also include other information, such as telephone and fax numbers and/or e-mail address, the name of the third person who introduced the person, and/or other types of person-identifying information.

Each of the digital face images stored in the profile database 13 is, for example, in the pixel matrix format. This means the profile database 13 stores the pixel data of each of the stored face images. In addition, the face feature data and the person-identifying data of each face image are associated with or linked to the respective face image stored in the profile database 13. The face feature data and the person-identifying data of a face image are, however, not necessarily physically stored adjacent to the respective face image in the profile database 13. The profile database 13 can be implemented and accessed using known database technologies. FIG. 6 shows the logical memory map 100 for the face images stored in the profile database 13.

As can be seen from FIG. 6, the logical memory map 100 of the profile database 13 of FIG. 1 includes a number of entries 101 through 100n, each for storing one digital face image. Each entry (e.g., the entry 101) includes a face feature data field (e.g., the face feature data field 101a), a person-identifying data field (e.g., the person-identifying data field 101b), and the image pixel data field (e.g., the pixel data field 101c). The pixel data field of each entry stores the pixel data (i.e., the image data) of a face image stored in the profile database 13. The face feature data field of each entry stores the face feature data of a face image stored in the database 13 and the person-identifying data field of each entry stores the person-identifying data of a face image stored into the database 13. The face feature data

computer's
function
data base.

field of an entry is associated with or linked to the face image of that entry. The person-identifying data field of an entry is also associated with or linked to the face feature data of that entry.

Referring back to FIG. 1, the input/output system 11 is used to input face images to the person identifier and management system 10. In addition, the input/output system 11 is also the output means of the person identifier and management system 10 for data output. For example, the input/output system 11 outputs the person-identifying data of a matching face stored in the person identifier and management system 10 by displaying or printing the person-identifying data. The input/output system 11 may include a number of input and output devices or modules. For example, the input/output system 11 may include a display that displays the input face image to be searched in the profile database 13 for matching faces. The display also displays any person-identifying data retrieved from the profile database 13. In addition, the input/output system 11 may also include a digital camera that captures the input face image. The digital camera may be replaced, for example, with a scanner. Moreover, the input/output system 11 may include a text input device (e.g., keyboard or touch sensitive screen with handwriting recognition capabilities) that allows input of text person-identifying data into the profile database 13. FIG. 5 shows one implementation of the input/output system 11 of FIG. 1, which will be described in more detail below.

As can be seen from FIG. 5, the input/output system 11 includes an I/O controller 51 connected to a number of I/O devices 52 through 56. The function of the I/O controller 51 is to control various input/output activities of the input/output system 11. The I/O controller 51 is implemented using known VO controller technologies.

The I/O devices 52-56 include a camera 52, a display 53, a scanner 54, a sensitive pen 55, and other I/O devices 56. The camera 52 can be any known digital camera. The display 53 can be any known computer or TV display. In one embodiment, the display 53 is a touch sensitive screen display that allows text and/or graphics input using a sensitive pen. In this case, the touch sensitive screen display may have an embedded keyboard or may have a handwriting recognition system. All of the I/O devices 52-55 can be implemented using known technologies.

The other I/O devices 56 may include a keyboard, a printer, and a modem or network adaptor for network communications. All the other I/O devices 56 are known I/O devices. Although FIG. 5 shows I/O devices 52-56 for the input/output system 11, the input/output system 11 may include more or fewer than I/O devices 52-56. For example, the input/output system 11 may not include the scanner 54.

Referring back to FIG. 1, the analysis system 12 of the person identifier and management system 10 is used to detect the face from the input face image supplied from the input/output system 11. In addition, the analysis system 12 extracts face feature data from the detected face in the input face image. The analysis system 12 then uses the extracted face feature data to search the profile database 13 for matching face feature data stored. If matching face feature data is located in the profile database 13, then the analysis system 12 retrieves the person-identifying data associated with the matching face feature data stored in the profile database 13. When the user of the person identifier and management system 10 views the retrieved person-identifying data, the user is able to recognize or identify the input face image.

INPUT / OUTPUT SYSTEM
↓
DISPLAY +
CAMERA A

If no matching face feature data is found in the profile database 13, it means that none of the stored face images in the profile database 13 is similar to the input face image. In this case, the analysis system 12 makes such indication to the user. The user can then have the option of storing the input face image in the profile database 13, along with the associated face feature data and the person-identifying data. Before storing the input face image into the profile database 13, the analysis system 12 asks the user to input the person-identifying data of the input face image via the input/output system 11. The structure and function of the analysis system 12 will be described in more detail below, also in conjunction with FIG. 4.

Referring to FIG. 4, the analysis system 12 includes a user interface 41, a search engine 42, and a face detection and feature extraction system 43. The user interface 41 is connected to the search engine 42 and the face detection and feature extraction system 43. The search engine 42 is also connected to the face detection and feature extraction system 43. Each of the components 41-43 is a functional module and can be implemented by software, hardware, and firmware.

The user interface 41 is an interactive user interface that is part of an interactive window interface. The user interface 41 includes a window (not shown) that displays the input face image and the retrieved person-identifying data. In addition, the user interface 41 also includes a number of command or function buttons that can be activated using a user input device (e.g., mouse or sensitive pen). The user interface 41 may also include a touch sensitive screen keyboard or a hand writing recognition system. The user interface 41 can be implemented using any known technology.

The face detection and feature extraction system 43 receives the input face image from the user interface 41. The face detection and feature extraction system 43 detects if the input face image contains any face. The detection system 43 also detects the eye locations of the face in the input face image. The system 43 then uses the eye location data to compute the face feature data of the detected face. The face feature data are also referred to as face coefficient data.

In one embodiment, the detection system 43 uses neural network-based face detection technology to detect the face in the input face image. The neural network-based face detection scheme is disclosed in a publication entitled HUMAN FACE DETECTION IN VISUAL SCENES, by H. Rowley (har@cs.cmu.edu), S. Baluja (baluja@cs.cmu.edu), and T. Kanade (tk@cs.cmu.edu) in November 1995. The publication is available from Carnegie Mellon University's Internet site at "www.ius.cs.cmu.edu/IUS/har2/har/www/CMU-CS-95-158R/." Alternatively, other known face detection technologies may be used. For example, a face detection scheme described in U.S. Pat. No. 5,164,992, dated Nov. 17, 1992, and entitled FACE RECOGNITION SYSTEM can be employed.

When the detection system 43 uses the neural network-based face detection scheme, the detection system 43 detects if the input face image contains any face by first applying a set of neural network-based filters to the image. The filters examine each location in the image at several scales, looking for locations that might contain a face (i.e., looking for eye locations). The detection system 43 then uses an arbitrator to combine the filter outputs. The arbitrator is used to merge detections from individual filters and eliminate overlapping detections. Using the neural network-based face detection technology makes the face detection robust, relatively fast,

Second
input

and detect most faces. In addition, it allows the detection system 43 to detect different kinds of faces with different poses and lightings.

Once a face is detected, the face detection and feature data extraction system 43 computes the face feature data of the detected face. In one embodiment, the face detection and feature extraction system 43 computes the face feature data of the detected face using a face feature extraction technology described in the above-mentioned U.S. Pat. No. 5,164,992. Alternatively, other known face feature extraction schemes may be used.

The face feature extraction process by the system 43 is done by first normalizing, warping (i.e., rotating and scaling), and masking the face to produce a reference face that has a set of predetermined eye locations. This means that through normalizing, warping, and masking of the detected face, the eyes of the detected face are mapped into the predetermined eye locations of the reference face. This is done by translating, scaling, and rotating the detected face and by adjusting the brightness and contrast of the detected face. In other words, this is to standardize or normalize the detected face. This is disclosed in the above-mentioned U.S. Pat. No. 5,164,992.

Then the system 43 projects the standardized face into an Eigen-face space to compute the face coefficients or face feature data of the detected face. This is also disclosed in the above-mentioned U.S. Pat. No. 5,164,992.

After the face detection and feature extraction system 43 extracts the face feature data, the extracted face feature data is then sent to the search engine 42. The search engine 42 then accesses the profile database 13 (FIG. 1) with the extracted face feature data. This is to find and locate any face feature data stored in the profile database 13 that matches or is similar to the extracted face feature data.

The search engine 42 uses the extracted face feature data to search for face images stored in the profile database 13 having similar face feature data. The search engine 42 compares the extracted face feature data with each stored face feature data to output similarity scores based on the predetermined similarity measure. In one embodiment, the similarity measure includes a set of thresholds and the face feature data includes a set of values. The comparison of the corresponding values of two face feature data yields differences between the values of the two data. The differences are then compared against their corresponding thresholds. A similarity score is obtained based on how many of the differences are less or more than the thresholds. The search engine 42 can be any kind of known search engine.

The search engine 42 then retrieves the person-identifying data associated with the matching face feature data (i.e., the similar faces) from the profile database 13. In one embodiment, the search engine 42 retrieves both the person-identifying data and the pixel data of the similar images for display after a search. In another embodiment, the search and engine 42 selectively retrieves the person-identifying data of the similar images in accordance with their similarity scores.

When there is no matching face feature data in the profile database 13 and the input face image is to be stored in the profile database 13, the face detection and feature extraction system 43 extracts the face feature data from the input face image and associates the face feature data with the input face image before storing the image and the face feature data into the profile database 13. In addition, the face detection and feature extraction system 43 receives the person-identifying data of the input face image from the user interface 41 before

storing the pixel data and the face feature data of the input face image into the profile database 13. The person-identifying data of the input face image is also associated with the face feature data of the input face image in the profile database 13.

Referring back to FIG. 1, the person identifier and management system 10 can be a portable personal system that can be easily carried around by the user of the system 10. For example, the person identifier and management system 10 can be a hand-held personal system. Alternatively, the person identifier and management system 10 can also be a non-portable system. FIG. 2 is a perspective view of a hand-held portable personal person identifier and management system 20 that implements one embodiment of the person identifier and management system 10 of FIG. 1. FIGS. 3A and 3B show the front and top views of the hand-held portable personal person identifier and management system 20.

As can be seen from FIGS. 2 and 3A-3B, the hand-held portable personal person identifier and management system 20 includes a touch sensitive screen display 22 that allows display of the input face image 24 and the retrieved person-identifying data 25 and a digital camera 23 that is an integrated part in the hand-held portable personal person identifier and management system 20. The digital camera 23 is used to capture the input face image 24. In addition, the hand-held portable personal person identifier and management system 20 also include a writing tool 21 that allows input into the hand-held portable personal person identifier and management system 20 via the touch sensitive screen display 22.

In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however, be evident to those skilled in the art that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A person identifier and management system, comprising:
 - (A) an image database that stores face feature data of each of a plurality of face images and person-identifying data associated with each of the face images, wherein the person-identifying data include name, affiliation, and time and occasion of meetings;
 - (B) an image capturing system that captures an input face image;
 - (C) a face analysis system coupled to the image capturing system and the image database to locate and retrieve the person-identifying data of any stored face image similar to the input face image from the image database;
 - (D) a display system that displays the input face image and the person-identifying data of the stored face image determined to be similar to the input face image by the face analysis system, wherein the person identifier and management system is a single stand-alone portable hand held device that fits into a user's single hand, wherein the image database, the image capturing system, the display system, and the face analysis system all physically reside in the single stand-alone portable hand held device.
2. The person identifier and management system of claim 1, wherein the face analysis system locates and retrieves the

person-identifying data from the image database by extracting the feature data of the input face image and comparing the face feature data of the input face image with that of each of the face images stored in the face image database.

3. The person identifier and management system of claim 1, wherein the face analysis system further comprises

(I) a face detection and feature extraction system that detects the input face image and extracts the face feature data from the input face image;

(II) a search engine that compares the face feature data of the input face image with that of the face images stored in the image database.

4. The person identifier and management system of claim 3, wherein the face analysis system further comprises a user interface that allows the input face image and the person-

identifying data to be displayed on a display and that allows a user to input and associate the person-identifying data with a face image displayed.

5. The person identifier and management system of claim 1, wherein the image capturing system is an integrated digital camera.

6. The person identifier and management system of claim 1, further comprising a display that displays the person-identifying data along with the input face image.

7. The person identifier and management system of claim 6, wherein the display is a touch screen display that also allows input of the person-identifying data into the face image database.

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